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November 1993

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US Army Corps
of Engineers
Waterways Experiment
Station

Ship Navigation Simulation Study, San Juan Harbor, San Juan, Puerto Rico

by Dennis W. Webb
Hydraulics Laboratory

WES

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Prepared for U.S. Army Engineer District, Jacksonville

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Final report

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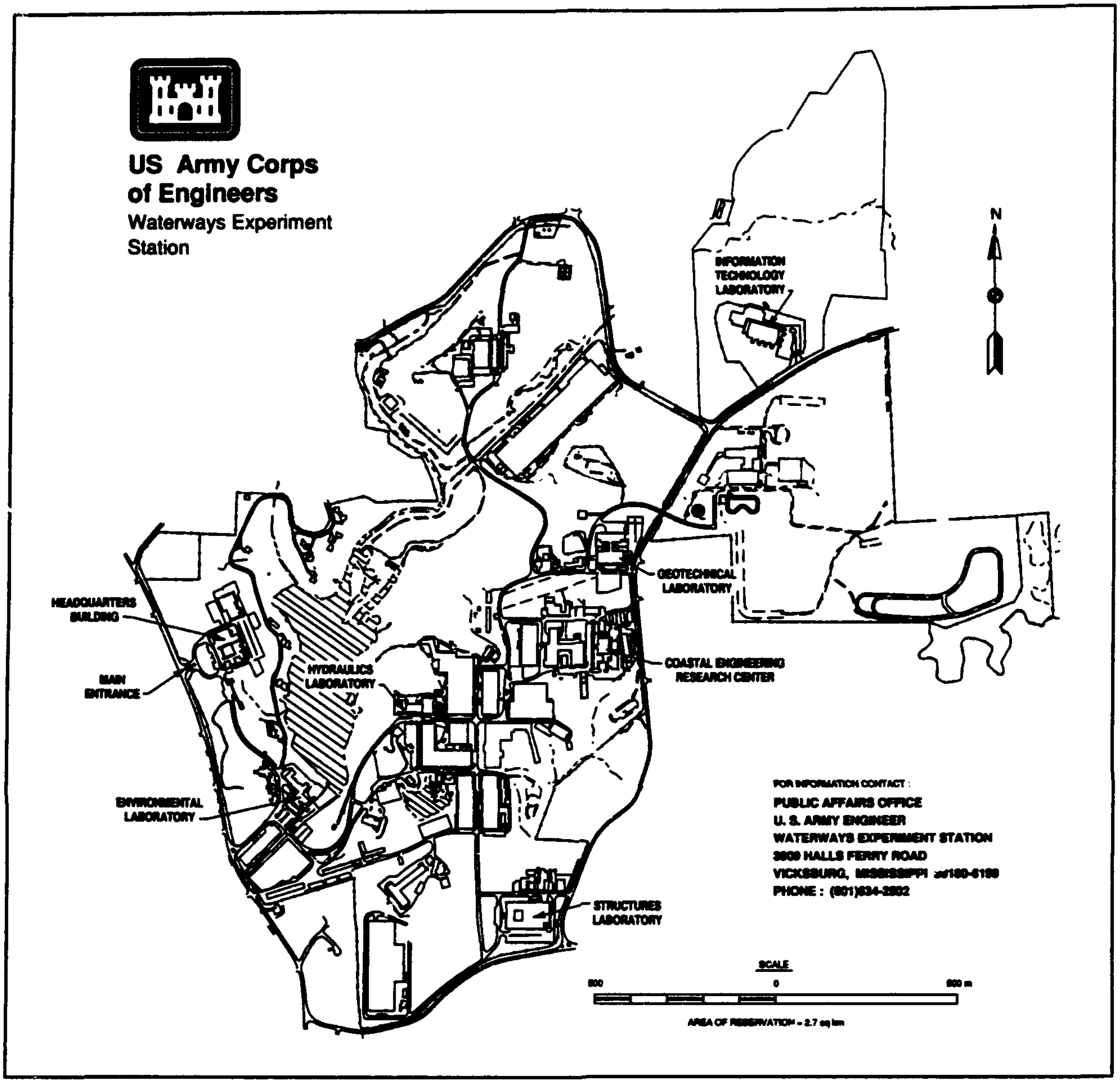

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Contents

List of Figures

Preface

This investigation was performed by the Hydraulics Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Jacksonville (SAJ). The study was conducted with the WES research ship simulator during the period April 1992-March 1993. SAJ provided survey data of the prototype area. Current modeling was conducted by the Estuarine Engineering Branch, Estuaries Division, Hydraulics Laboratory.

The investigation was conducted by Mr. Dennis W. Webb of the Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general direction of Messrs. Frank A. Herrmann, Jr., Director, Hydraulics Laboratory; Richard A. Sager, Assistant Director, Hydraulics Laboratory; M. B. Boyd, Chief of the Waterways Division; and Dr. Larry L. Daggett, Chief of the Navigation Branch. Ms. Peggy Selden, Civil Engineering Technician, Navigation Branch, assisted in the study. Mr. Samuel B. Heltzel, Estuarine Engineering Branch, prepared Appendix A. This report was prepared by Mr. Webb.

Acknowledgment is made to Messrs. Mike Choate and Robert Newman, SAJ, for cooperation and assistance at various times throughout the investigation. Special thanks go to the San Juan Harbor Pilots Association for participating in the study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Background

San Juan is located on the northern coast of the Commonwealth of Puerto Rico (Figure 1). Puerto Rico, being a relatively small island, is heavily dependent on oceangoing vessels for the import of many items. San Juan Harbor (Figure 2) is the largest port on the island and the fifth largest container port in the world. Noncontainerized cargo, such as petroleum products, lumber, grains, automobiles, and steel, is also imported to the island via ships. Rum, Puerto Rico's principal export, is shipped in containers. Cruise vessels also call frequently on San Juan Harbor.

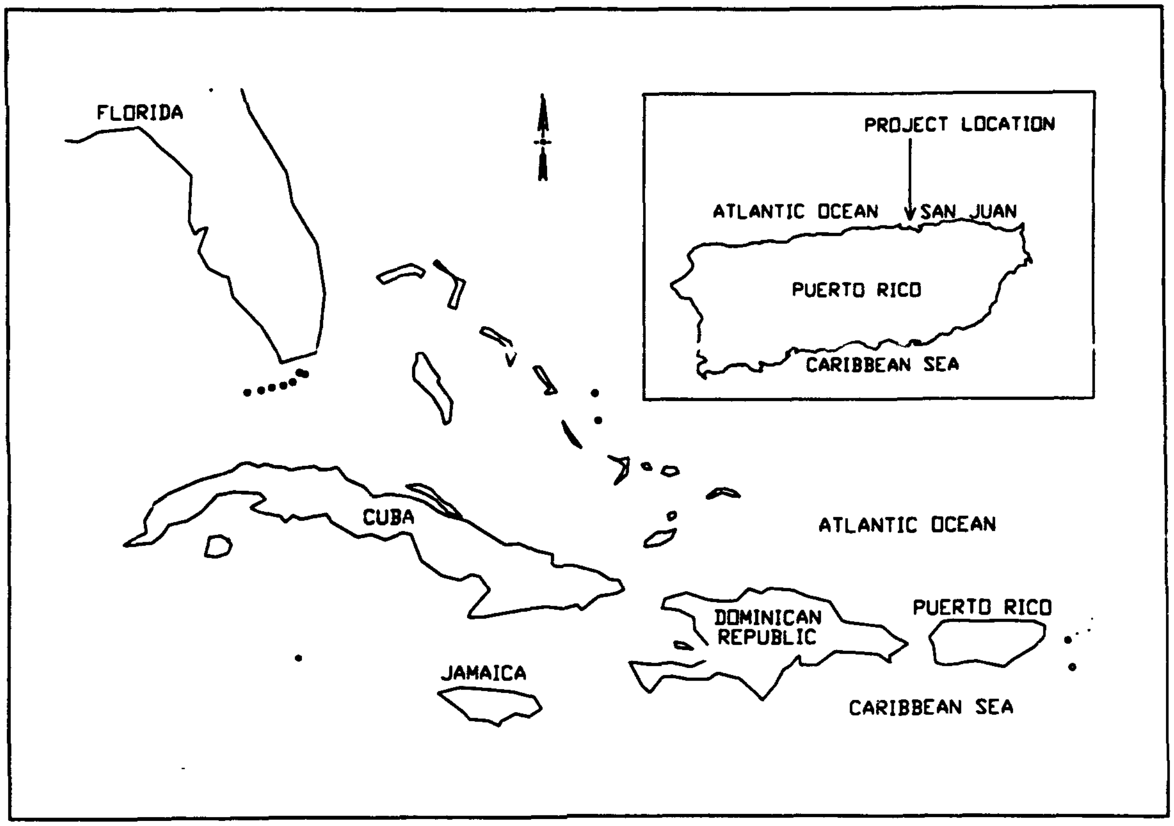
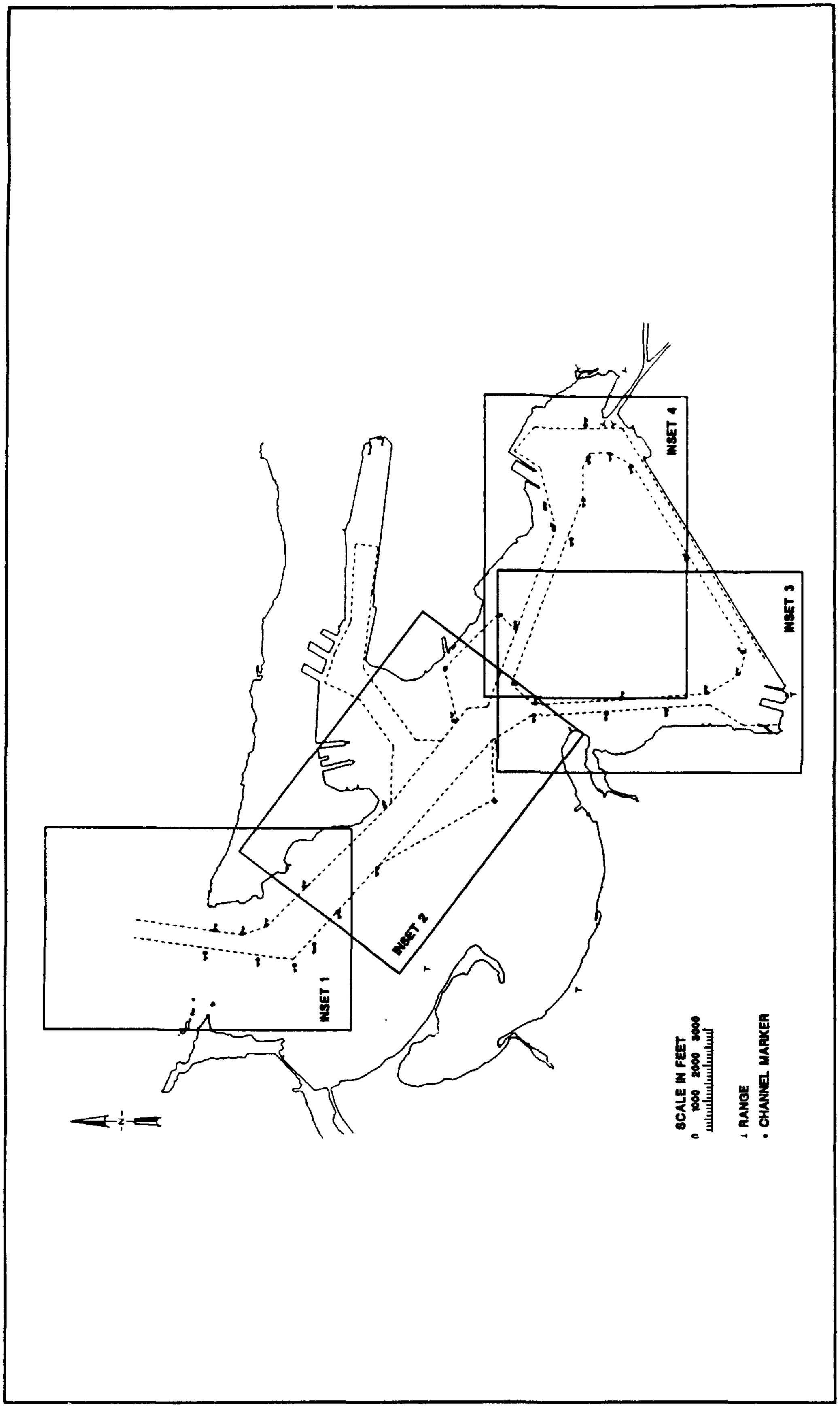


Figure 1. Project vicinity map



a. Plan

Figure 2. San Juan Harbor (Sheet 1 of 5)

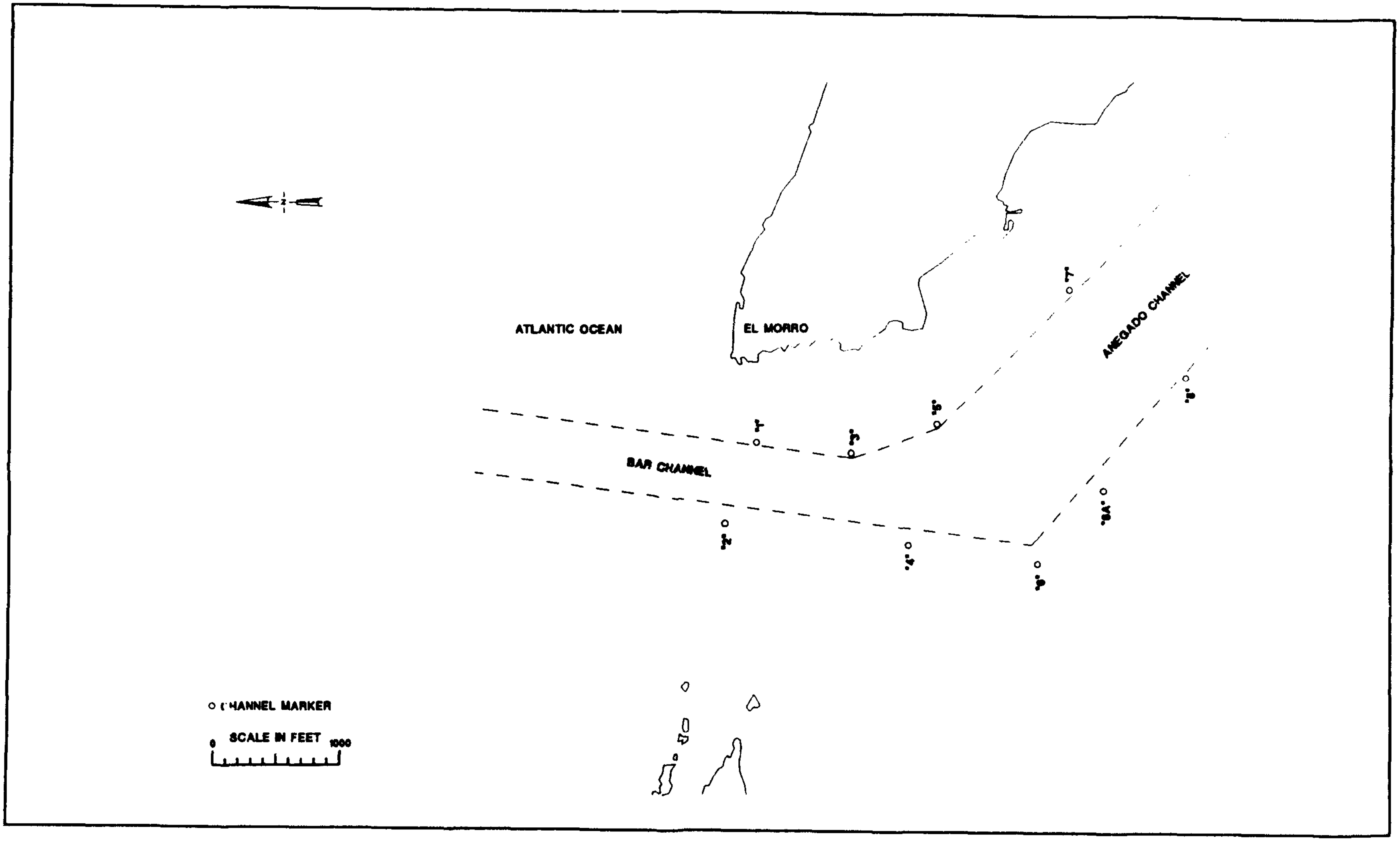


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Figure 2. (Sheet 2 of 5)

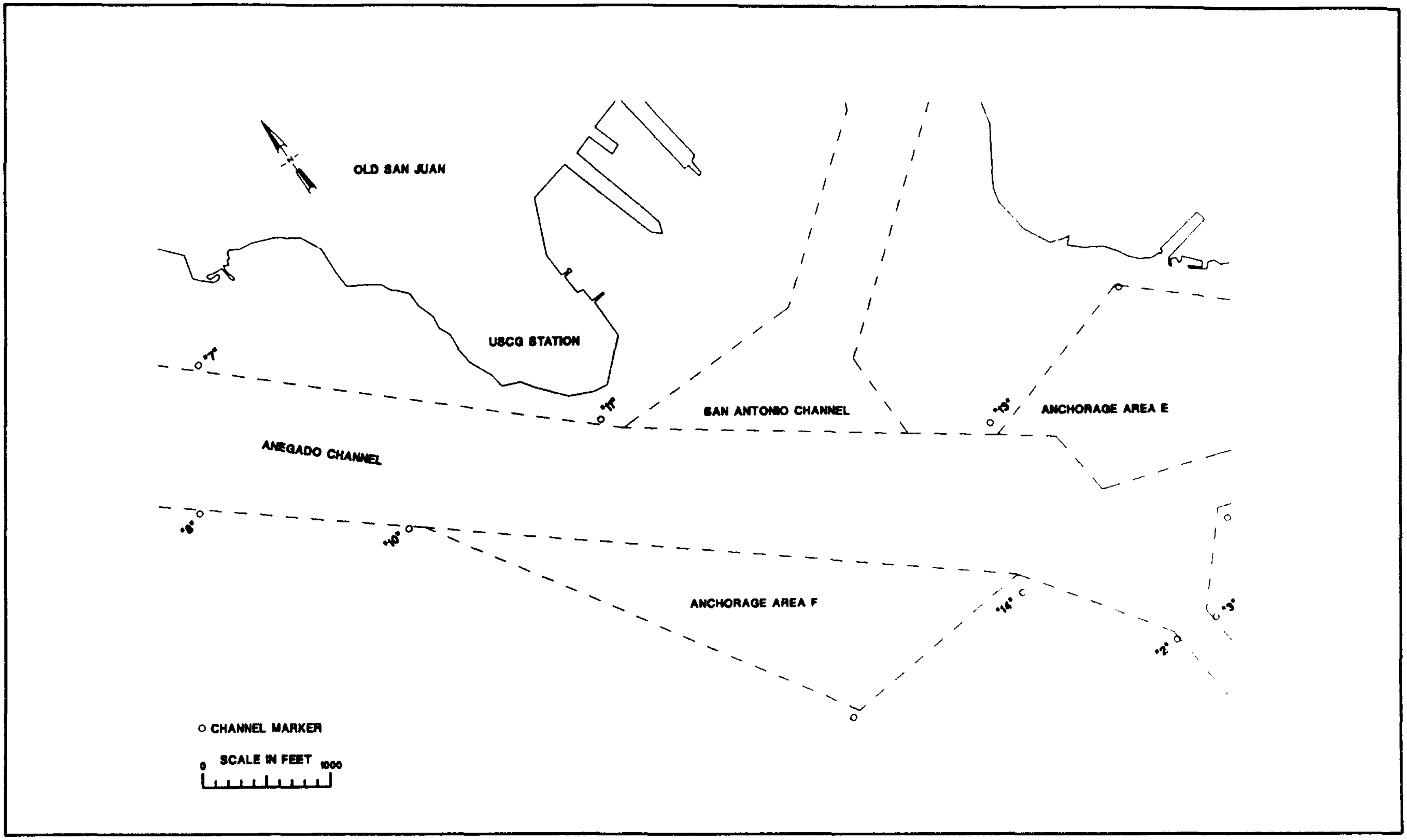

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Figure 2. (Sheet 3 of 5)

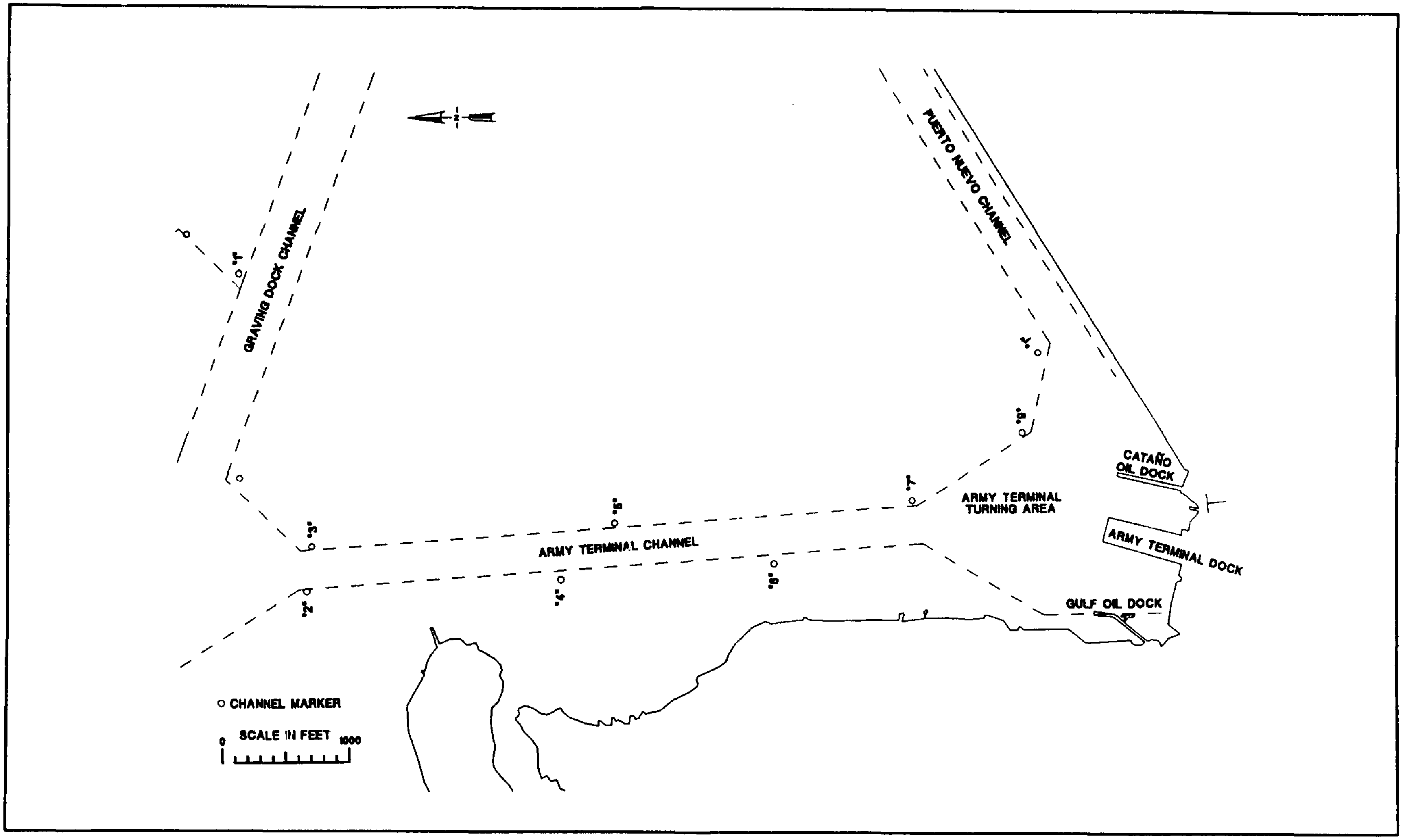

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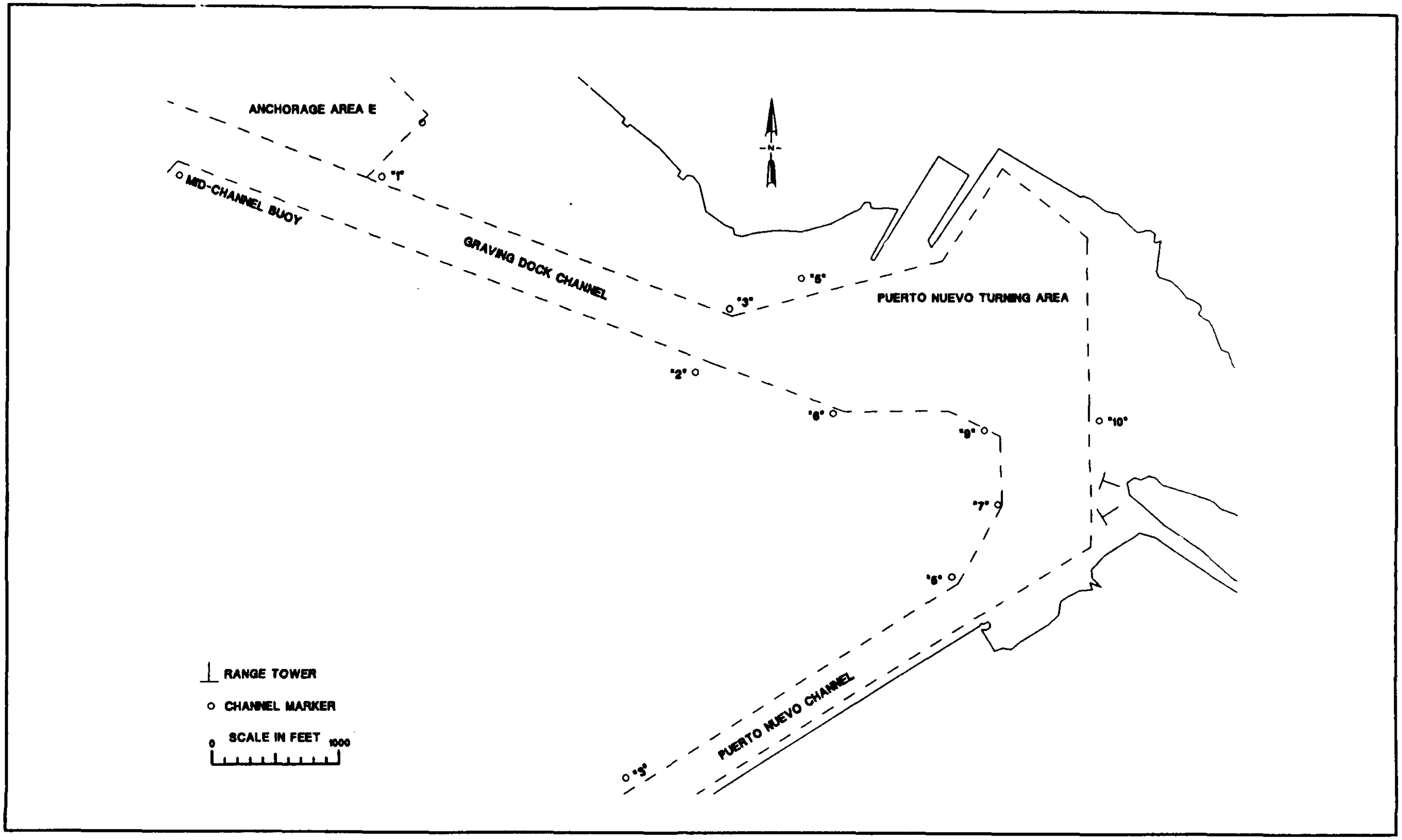
 Figure 2. (Sheet 4 of 5)



e. Inset 4

Figure 2. (Sheet 5 of 5)

Existing Conditions and Navigation Problems

The present harbor channels as maintained by the U.S. Army Engineer District, Jacksonville, have the following dimensions:[1]

Channel Segment	Depth, ft	Width, ft
Bar Channel	38 - 45	500
Anegado Channel	36 - 38	1,000 - 1,200
Army Terminal Channel	36	300
Puerto Nuevo Channel	32	300
Graving Dock Channel	30	400

The Bar Channel and the northernmost portion of the Anegado Channel are deeper than the other channels to allow for the vertical motion of the vessel due to waves at the entrance to the harbor.

Entrance Channels

The Bar Channel and the turn between the Bar Channel and Anegado Channel are considered the most difficult parts of the San Juan Harbor (Figure 2b). There are a number of factors that contribute to this situation. Wind, wave, and swell conditions are important factors in navigating the harbor entrance. Winds are usually steady and are described as being between 15 and 20 knots predominantly from the east and northeast. Long fetches to the east allow the development of constant east and northeast swells of about 3-12 ft in height in the deep water offshore. At times, large waves (up to 22 ft) approach from the north due to storms north of the island. These conditions make it difficult for a pilot to approach and board ships entering the harbor. Under less severe conditions, pilots board a vessel when it is 3 miles from the harbor entrance. However, the pilots report that sometimes it is too dangerous to board ships outside the harbor entrance channel and the ship's captain will bring the ship into the Bar Channel without a pilot, at which time the pilot will board. Additionally, pilots must sometimes disembark vessels prior to the ship's clearing the last pair of buoys, due to these same conditions. The pilots expect that their recent acquisition of two new larger and more powerful pilot boats will alleviate this situation.

These same conditions of wind and waves also make navigating the entrance channel and negotiating the turn between the Bar Channel and the Anegado Channel difficult. Ships must maintain headway for control and steerage as they come through the entrance channel, but must slow in order to make this relatively sharp turn. The U.S. Coast Guard (USCG) reports that all

1 A table of factors for converting non-SI units of measure to SI units is found on page vi.

the documented accidents that have occurred in recent years (six in the last 2 years) are groundings that have occurred on the south side of this turn. It has also been pointed out by captains and pilots that the outbound ships have difficulty making this turn since in addition to being on the inside of the turn, the ship is going from a relatively wide channel into a narrower channel. The Bar Channel is so narrow that the ships end up on the west side of the channel after completing the turn.

While generally the currents are considered small, less than 1 fps, the currents are the strongest in the Bar Channel. In addition, the waves entering the harbor refract and induce some currents. During flood tide, currents will combine with the wave-induced currents, the wind, and waves to produce the most difficult combination of navigation conditions at this harbor. The bluffs on the east side of the Bar Channel are very high and block the wind for portions of the transit of this channel between El Morro and the USCG Station. El Morro is a historic fort built on the bluffs near Old San Juan to protect San Juan Harbor from attack and is of major historic significance. Wind speeds in the inner harbor south of the USCG Station are typically 50 to 75 percent of those in the Bar Channel north of El Morro.

In addition to the physical forces and channel size affecting ship handling, the navigation ranges for this channel are difficult to see, particularly the rear range marker. The rear range mark appears to be located too low and blends in with the trees. Lights on these ranges are shut on and off by a light sensor; however, the light sensitivity is set low and the lights sometimes go off before the marks can be clearly seen at daybreak or sunset. Some complaints about the lighting of the buoys (e.g., flashing and/or colors) in the entrance have also been voiced.

Army Terminal-Puerto Nuevo Turn

The second most difficult navigation conditions are considered to be the turn between the Army Terminal and Puerto Nuevo Channels (Figure 2d). Tanker terminals located in this turn are used for discharging oil, gasoline, liquid propane gas (LPG), and other fuels. Under present conditions, there is not enough room for loaded ships calling at these docks to turn and dock bow-out. It is typically considered safe practice to dock tankers bow-out (because of the explosive nature of their cargo) so that they are ready to sail in case of emergency. It is not uncommon for large ships docked at Cataño Oil Dock to extend up to 100 ft into the navigation channel. In the future, larger ships calling at this terminal will create even more of an obstruction. Inbound loaded container ships and bulk cargo and car carriers use this channel and turn to enter the Puerto Nuevo Channel. With strong winds, controlling these ships, particularly the large container ships and blocky car carriers, is difficult. Under present operations, tankers exit the harbor through the Army Terminal Channel.

Puerto Nuevo-Graving Dock Turn

The turn between the Puerto Nuevo and Graving Dock Channels is a very severe turn (Figure 2e), and presently there is a point that makes this turn very difficult. Sediment and currents coming out of the Puerto Nuevo River enter the harbor at this point, and these affect navigation of this turn. In order to go around this point, the ship must get out of line with the ranges marking this channel and typically remain out of alignment with the ranges for a considerable distance through the eastern part of the channel. While most ships unload in the Puerto Nuevo Channel and depart with light loads or in a ballasted condition through this turn and into the Graving Dock Channel, many of the modern container ships carry empty containers and are subject to wind effects as they make this turn. Car carriers likewise will be affected by the wind due to their large area above the waterline. New longer ships that may call on the improved project are expected to have difficulty with this turn as well as with the Army Terminal-Puerto Nuevo Turn.

Army Terminal Channel

Pilots indicated that the Army Terminal Channel has a tendency to shoal on the west side where a side channel enters the harbor. In addition the ranges that mark this channel are near the tanker terminals and are difficult to see clearly. There is a concern that with the proposed improvements to the project, loaded larger tankers might have trouble making the turn between the Anegado and Army Terminal Channels.

Proposed Improvements

In order to address these navigation concerns and to allow deeper drafted vessels to call at San Juan Harbor, two proposed channel alternatives (Plan 1 and Plan 2) were developed. The two plans differ in channel width and alignment, but not in depth. Plans 1 and 2 are not exclusive of each other; therefore the final recommendation may consist of portions of both plans. The proposed depths of the Bar Channel and the northern portion of the Anegado Channel were to be determined during the ship simulation project via a separate vertical motion study. The depth of the remainder of the Anegado Channel remains 39 ft. The Jacksonville District will determine the depth of the Army Terminal, Puerto Nuevo, and Graving Dock channels by economic analysis after completion of the ship simulation study. The Jacksonville District informed the U.S. Army Engineer Waterways Experiment Station (WES) that they expected the depths to be approximately 39 ft for Army Terminal and Puerto Nuevo channels and 36 ft for Graving Dock Channel.

Plan 1 (Figure 3) was developed by the Jacksonville District.[1] Plan 1 calls for the Bar Channel to be widened to 800 ft and shifted west, but maintain its present heading. The shift west is to allow the channel to be deepened without undermining El Morro. Plan 1 also narrows the northern portion of the Anegado Channel on the eastern side to protect El Morro; widens the Army Terminal and Puerto Nuevo channels to 450 ft, while the width of the Graving Dock Channel remains 400 ft; and widens the west side of the turn between Anegado Channel and Army Terminal Channel. The Army Terminal Turning Area is widened to allow inbound tankers to be turned and docked port side to the Gulf Oil Dock and to allow container ships additional room when turning into the Puerto Nuevo Channel. The Puerto Nuevo Turning area is widened on the west side to ease the turn from Puerto Nuevo into Graving Dock Channel.

Plan 2 (Figure 4) was developed at WES to test a different alignment for the Bar Channel, less bend widening, and less widening of straight channel sections in the inner harbor area. The Plan 2 Bar Channel maintains the 800-ft width of the Plan 1 Bar Channel, but changes alignment by rotating the northern end of the channel to the west. This was done to reduce the angle between the Bar Channel and the Anegado Channel and was developed at the recommendation of several pilots and cruise ship captains. The change in heading of the Bar Channel will allow the ships to be headed in a direction that will allow more lee side protection from waves so that the pilots may board ships offshore under wave conditions that are not possible now. Hydrographic surveys indicate that although the Plan 2 Bar Channel does not overlap as much of the existing channel (and therefore takes advantage of the existing depth) as the Plan 1 channel, it would require nearly the same dredging as (and possibly a little less than) the Plan 1 channel. This is because the water is naturally deep in this area, and because the widener between the Bar Channel and the Anegado Channel is not as wide as Plan 1. In order to decide if safe navigation in the proposed Army Terminal and Puerto Nuevo channels could be obtained with less dredging, widths were reduced from the Plan 1 width of 450 ft to 350 ft. The other changes from the Plan 1 channels are not widening the bend between Anegado and Army Terminal channels and significantly reducing the Puerto Nuevo Turning Area. The Army Terminal Turning Area is identical for Plans 1 and 2.

Purpose and Scope

In order to evaluate the proposed plans for channel improvement, a real-time ship simulation investigation was conducted. The purpose of the study was to determine the effects of the proposed improvements on navigation and to optimize the required channel width and alignment required to safely and

[1] U.S. Army Engineer District, Jacksonville. (1981). "Phase 1 General Design Memorandum on San Juan Harbor, Puerto Rico," Jacksonville, FL.

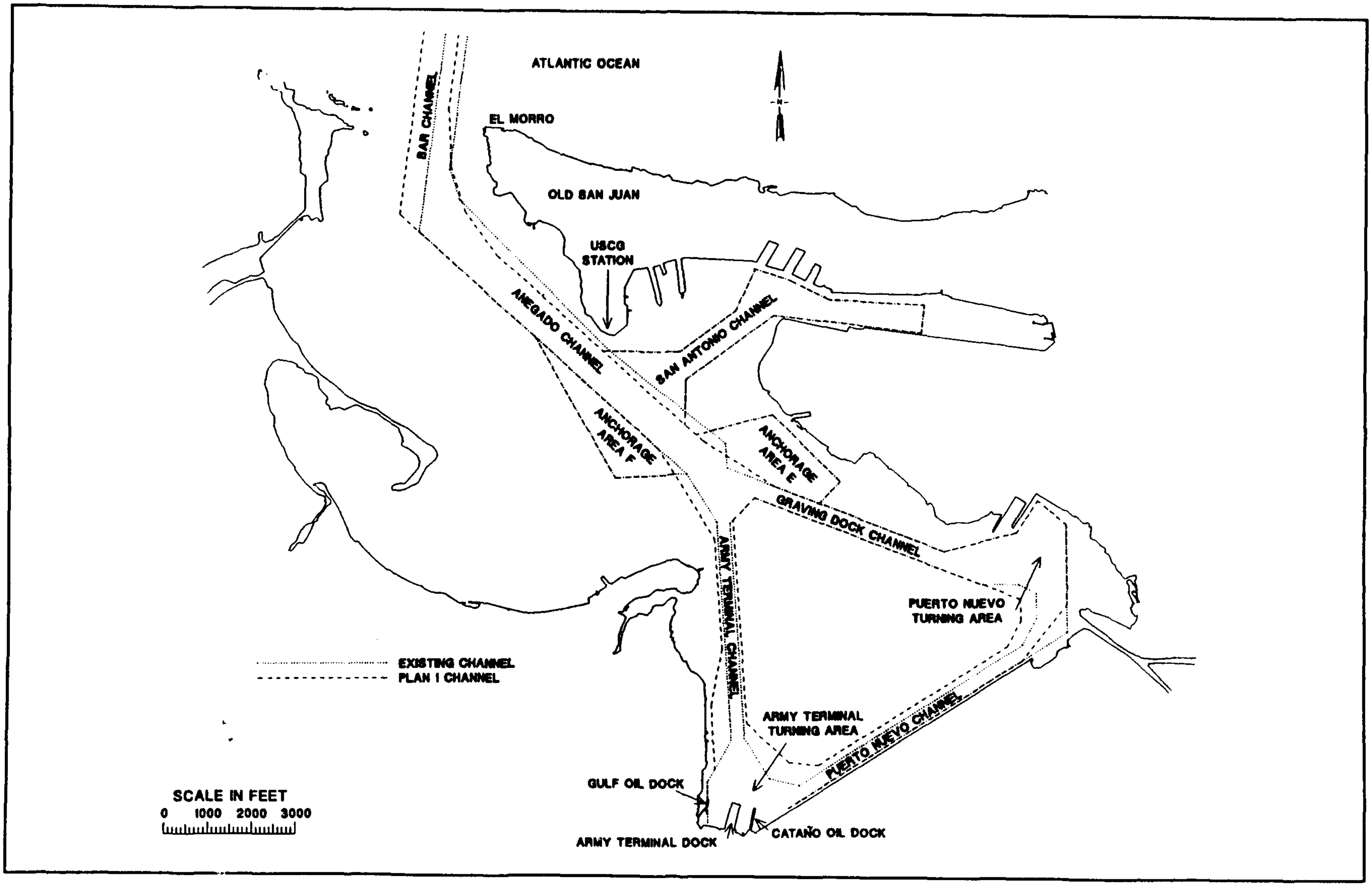


 Figure 3. Plan 1 channel configuration

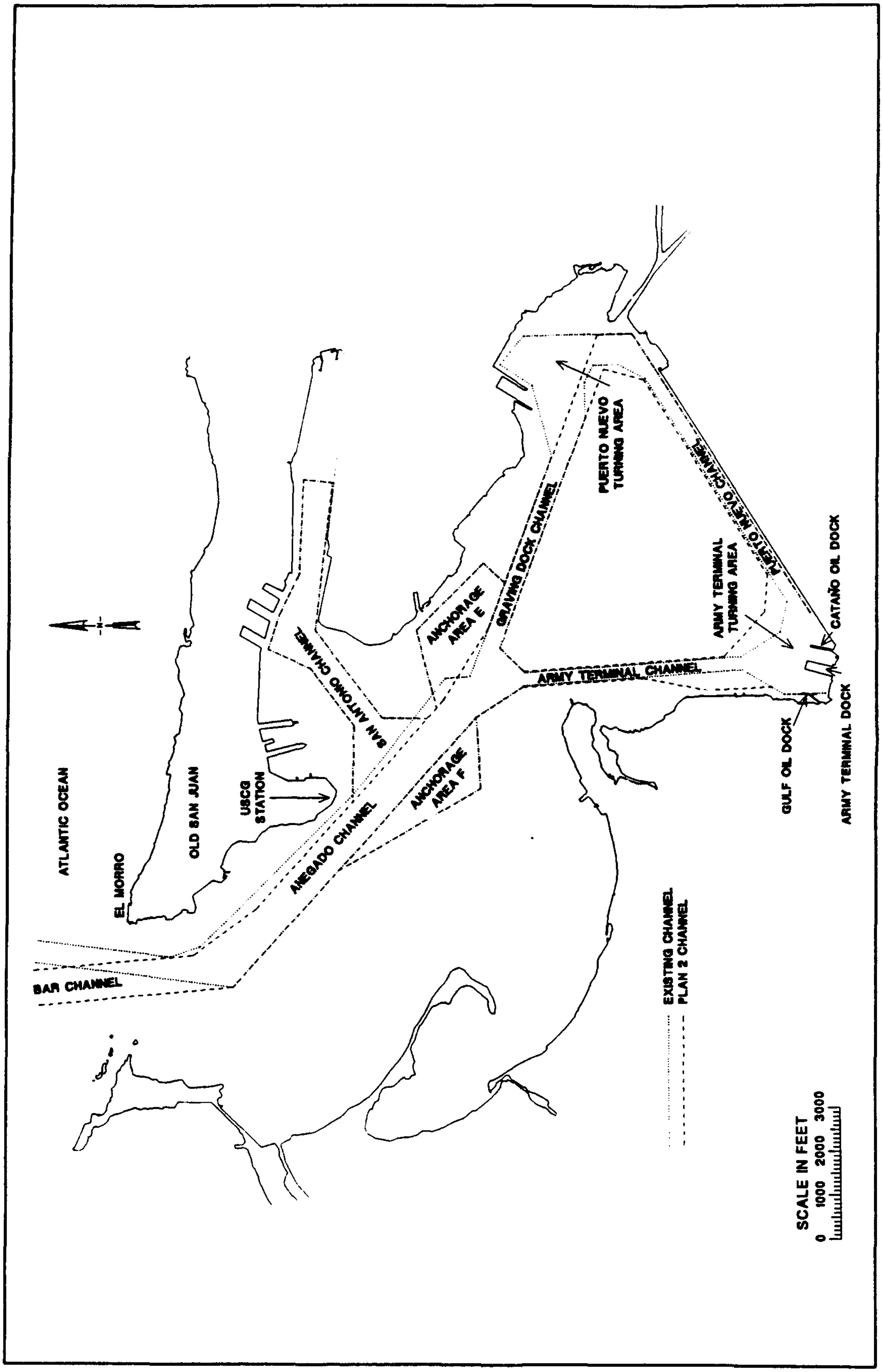


Figure 4. Plan 2 channel configuration

efficiently navigate the study area. Also, a vertical motion study was undertaken to determine the necessary depths in the Bar and Anegado channels to allow for the ship's vertical motion due to wave action.

2 Data Development

Description of Simulator

It is beyond the scope of this report to describe other than briefly the WES ship simulator.[1] The purpose of the WES ship simulator is to provide the essential factors necessary in a controlled computer environment to allow the inclusion of the man-in-the-loop, i.e., local ship pilots, in the navigation channel design process. The simulator is operated in real-time by a pilot at a ship's wheel placed in front of a screen upon which a computer-generated visual scene is projected. The visual scene is updated as the hydrodynamic portion of the simulator program computes a new ship's position and heading resulting from manual input from the pilot (rudder, engine throttle, bow and stern thruster, and tug commands) and external forces. The external force capability of the simulator includes effects of wind, waves, currents, banks, shallow water, ship/ship interaction, and tugboats. In addition to the visual scene, pilots are provided simulated radar and other navigation information such as water depth, relative ground and water speed of the vessel, magnitude of lateral vessel motions, relative wind speed and direction, and ship's heading.

Required Data

Data required for the simulation study included channel geometry, bottom topography, channel currents for proposed as well as existing conditions, numerical models of test ships, and visual data of the physical scene in the study area. Dredging survey sheets provided by the Jacksonville District were used for establishing channel alignment. Current data were obtained from a TABS-2 finite element numerical model of the San Juan Harbor Channels developed for navigation (Appendix A). A reconnaissance trip was carried out for the purpose of observing actual shipping operations in the study area. Still photographs were taken during the reconnaissance transits to aid in the generation of the simulated visual scene. Discussions with pilots were also held

1 "Hydraulic Design of Deep Draft Navigation Channels," PROSPECT (Proponent Sponsored Engineer Corps Training) course notes, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 19-23 June 1989.

during this trip so that WES engineers could become more familiar with concerns and problems experienced during channel operations.

Test File

The test file contains initial conditions (ship speed and heading, rudder angle, and engine setting) for the simulation and geographical coordinates for the channel alignment. The channel is defined in terms of cross sections located to coincide with changes in channel alignment and current direction and magnitude. The information used for the development of the San Juan database was obtained from the District's project drawings. The Puerto Rico state plane coordinate grid was also plotted on these drawings and was used for the simulator database coordinate system. Also included in the test file are the steepness and overbank depth (water depth at the top of the side slope) adjacent to the channel. These data are used by the computer to calculate bank effect forces on the test vessels. Specifications of other external forces such as wind and waves are also included in this file.

For the San Juan project the simulator channel cross sections were placed approximately 500 ft apart except where the bends occurred or where channel width changed. Since the channels were fairly uniform, the simulator cross sections did not vary in spacing significantly. The simulator program handles the transition between cross sections on an interpolative basis.

Water depths for the simulator were based on authorized project depths. For the simulated existing channel, the water depth represented the existing condition taken from the most recent dredging survey furnished by the District. Also, bank slopes and overbank depths were obtained from the August 1990 District dredging survey. These data are used in the calculation of ship hull bank forces. Briefly, bank forces occur when a ship travels close to a submerged bank (also, wall or docked ship), and the resulting effect is characterized by a movement toward the bank and a bow-out rotation away from the bank.

Scene File

The scene data base comprises several data files containing geometrical information enabling the graphics computer to generate the simulated scene of the study area. The computer hardware and software used for visual scene generation are separate from the main computer of the ship simulator. The main computer provides motion and orientation information to a stand-alone graphics computer for correct vessel positioning in the scene, which is then viewed by the pilot. Operators view the scene as if they are standing on the bridge of a ship looking toward the ship's bow in the foreground. View direction can be changed during simulation for the purpose of looking at objects outside of the relatively narrow straight-ahead view.

Aerial photographs, navigation charts, and dredging survey charts provided the basic data for generation of the visual scene. The simulation testing required low visual resolution beyond the immediate vicinity of the navigation channel. All land masses in the vicinity of the navigation channel were included in the scene. All aids to navigation in the vicinity of the study area were included. In addition to the man-made and topographical features in the vicinity, the visual scene included a perspective view of the bow of the ship from the pilot's viewpoint. Visual databases for all design ships were developed at WES for use in the simulation.

Radar File

The radar file contains coordinates defining the border between land and water and significant man-made objects, such as docked ships and aids to navigation. These data are used by another graphics computer that connects the coordinates with straight lines and displays them on a terminal. The objects viewed comprise visual information that simulates shipboard radar. The main information sources for this database were the project drawings and dredging survey sheets supplied by the District.

Ship Files

The ship files contain characteristics and hydrodynamic coefficients for the test vessels. These data are the computer's definition of the ship. The coefficients govern the reaction of the ship to external forces, such as wind, current, waves, banks, underkeel clearance, and ship/ship interaction, and internal controls, such as rudder and engine revolutions per minute (rpm) commands. The numerical ship models for the San Juan simulations were developed by Tracor Hydronautics, Inc., of Laurel, MD.[1] The test ships were chosen based on the District's economic analysis of future shipping business and operations.

Current File

The current file contains current magnitude and direction and water depth for each of eight points across each of the cross sections defining the channel alignment. Current data for a ship simulation study are usually obtained from physical or numerical models. In this study, current data were available from

[1] V. Ankudinov. (1988). "Hydrodynamic and mathematical models for ship maneuvering simulations of "LASH" barge carrier and two bulk carriers in support of the Pascagoula Harbor study," Technical Report 87005.0623-1, Prepared under Contract No. DACW3987-D-0029 by Tracor Hydronautics, Laurel, MD, for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

a numerical model of San Juan Harbor (Appendix A). The model bathymetry was modified for generation of currents for the two proposed conditions.

Test Conditions

The test scenarios, design vessels, and environmental conditions were selected in order to test the existing and proposed channels in the "maximum credible adverse situation," that is, the worst conditions under which the harbor would maintain normal operations. This approach provides a built-in safety factor when analyzing the results. The existing channels were tested in order to provide a base with which to compare tests conducted in the proposed channels, and to provide a basis for comparison of conditions by the pilots involved in the testing.

Wind

A wind from the northeast was imposed on all simulation tests in San Juan Harbor. The wind module gusts randomly plus or minus 50 percent of the average wind speed. Wind effects are not uniform throughout San Juan Harbor. Vessels are shielded from wind in the reach from El Morro to the USCG Station by El Morro, bluffs, and tall buildings, and partially shielded in the inner harbor area. In order to accurately model ship response, the WES ship/tow model was modified so that wind speed could be changed as the vessel transited the test reach. A wind speed of 20 knots (Figure 5) was used in the Atlantic Ocean north of El Morro. The wind was calm between El Morro and the USCG Station. A 15-knot wind was used for the Anegado Channel south of the USCG Station and the Army Terminal Channel. A 10-knot wind was used for the Graving Dock Channel since, being on the east side of the harbor, it is more protected from a northeast wind. The wind for Puerto Nuevo Channel varied from 15 knots at its western end to 10 knots at its eastern end.

Waves

Waves used in the navigation study were modeled by WES.[1] Twenty years of hindcast wind and wave information was used to characterize the wind and wave climate offshore of the harbor entrance. Selected combinations of wave height, period, and direction from the offshore conditions were transformed through the harbor entrance using a numerical model. Results were compared to results obtained in a physical model study conducted in 1979.

[1] J. M. Hubertz, S. M. Bratos, W. A. Brandon, and R. Hoban. (1992). "San Juan Harbor Navigation Study, Wind and Wave Task," prepared for U.S. Army Engineer District, Jacksonville, Jacksonville, FL, by Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

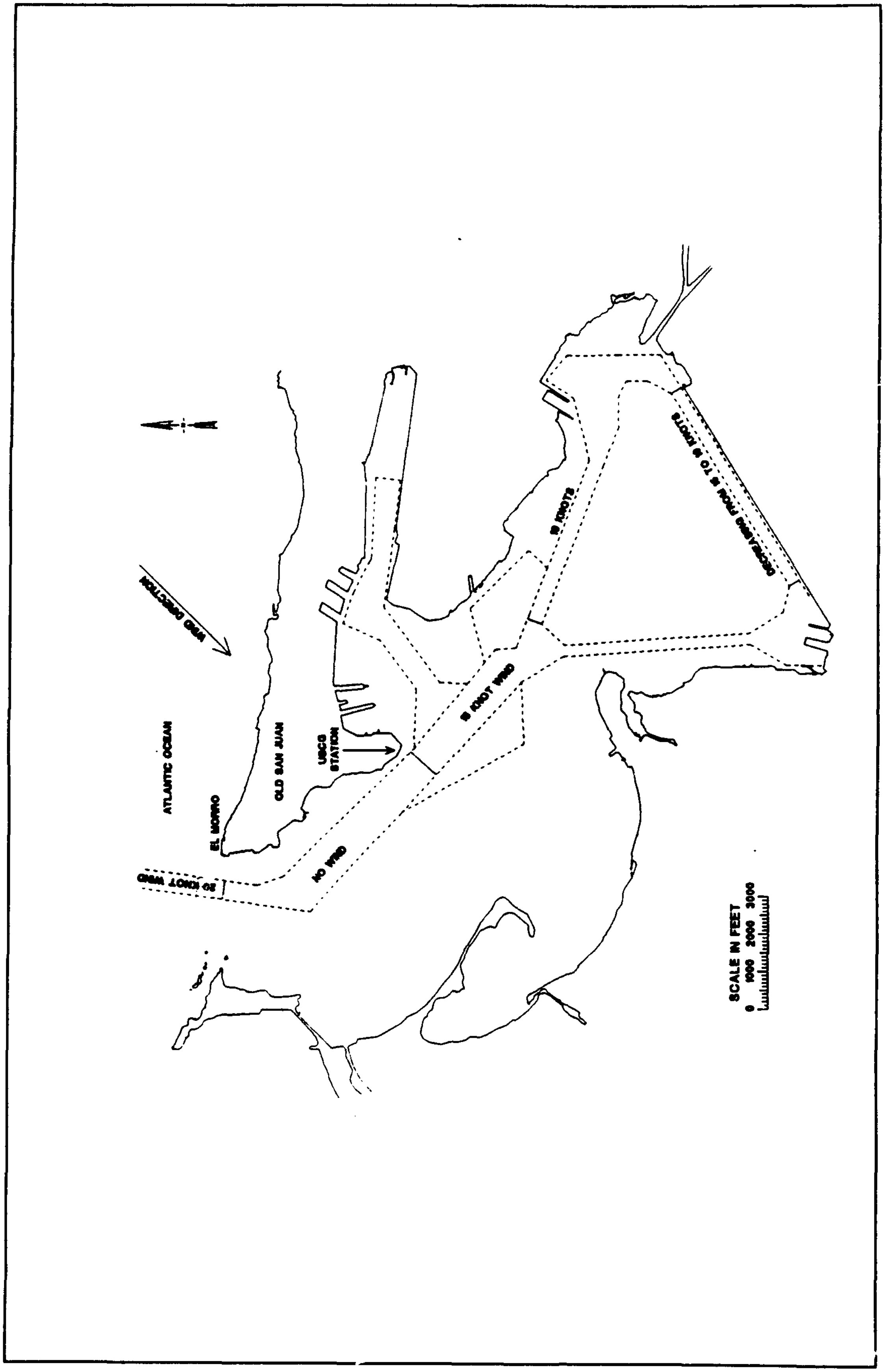


Figure 5. San Juan Harbor wind

Numerical and physical model results were in general agreement (on the average within 1.5 ft of each other), and both indicated a trend for rapid decay of wave energy progressing from offshore into the harbor. Wave conditions for moderate and heavy seas were estimated from the climatic summaries and transformed through the harbor entrance for existing and plan conditions.

A new software module to calculate the ship's response due to waves was developed under contract by a naval architect and installed prior to validation. Waves from the northeast of 15 ft were used in the ocean (Figure 6) until a point approximately 1,000 ft north of El Morro. At this point the waves gradually decreased to a height of 5 ft at El Morro. The wave height remained between 4 and 5 ft for another 1,000 ft, then decreased to zero after the turn from the Bar Channel into the Anegado Channel.

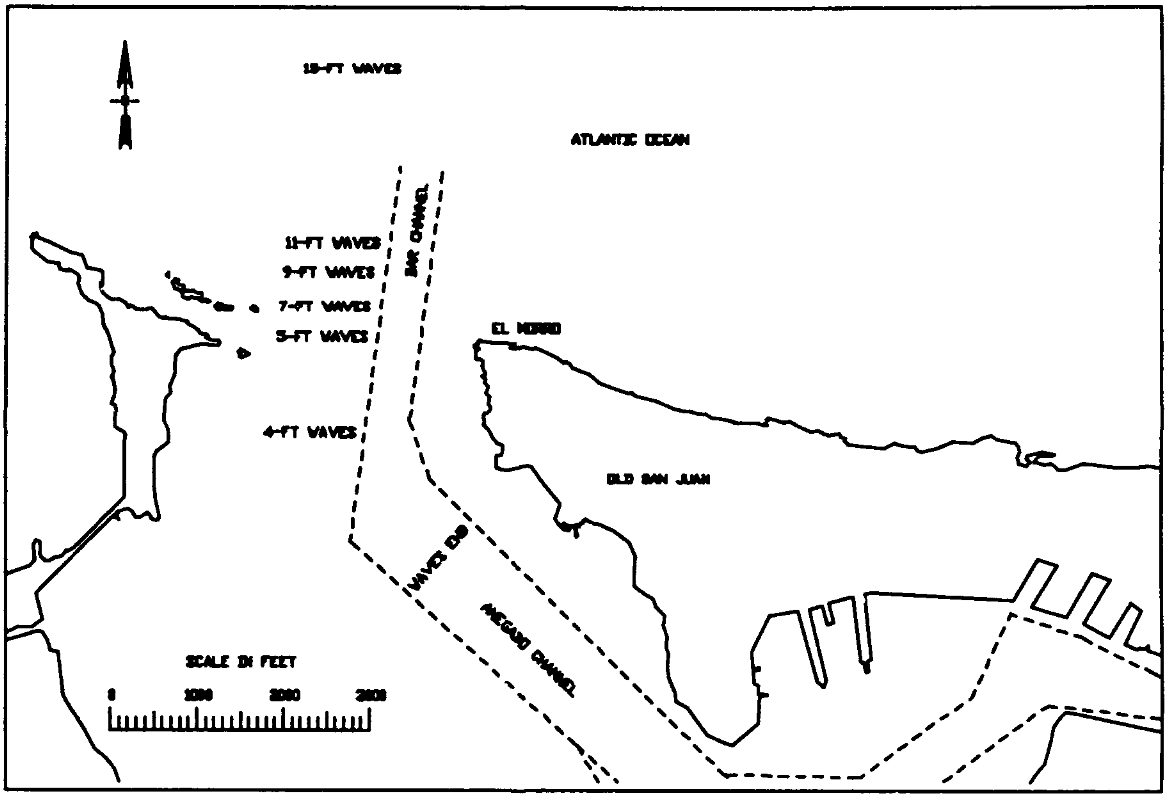


Figure 6. San Juan Harbor waves

Although the pilots would not be able under existing conditions to board a ship in 15-ft seas, ship captains will sometimes elect to bring the vessel into the harbor without a pilot. Therefore, the 15-ft ocean wave condition was selected as the test case for the simulation project.

Currents

Channel currents were derived from a TABS-2 model study conducted at

WES (Appendix A). Although the current was very small, all simulation tests were run with flood tide. When the validation pilots transited the Bar Channel on the simulator, they stated that they experience wave-driven crosscurrents of about 1 fps in the segment of the Bar Channel north of El Morro. These currents were put into the model and the pilots were satisfied with the vessel's response.

Design vessels

The design ships for the simulation of San Juan Harbor were a 763-ft × 125-ft tanker and a 810-ft × 106-ft container ship. The tanker, when inbound, was loaded to a 32-ft draft for the existing condition and 36 ft for the proposed conditions. The tanker, when outbound, was in ballast at a draft of 26 ft. The container ship was loaded to a 32-ft draft for the existing condition and 36 ft for the proposed conditions, for both inbound and outbound runs. The length of all vessels is given as the length between perpendiculars.

3 Navigation Study

Validation

The simulation was validated with the assistance of two pilots licensed for San Juan Harbor. The following information was verified and fine tuned during validation:

a. Wind effects.

b. Bank conditions.

c. Waves and currents.

d. Ship engine and rudder response

e. The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location and orientation of the docks.

(3) Location of buildings visible from the vessel.

Validation began by the pilots maneuvering through the visual scene in a fast-time mode in order to quickly check building and buoy locations. After this was done, real-time simulation runs were undertaken with the vessel transiting the entire study area. Special attention was given by the pilot to the response of the ship due to external forces. Problem areas were isolated, and the prototype data for these areas were examined. The model was then adjusted and further simulation runs were then undertaken through the problem areas, anu if necessary, additional adjustment was made. This process was repeated until the pilot was satisfied that the simulated vessel response was similar to that of an actual vessel in the prototype.

Test Scenarios and Procedure

In order to completely analyze the proposed channels, inbound and outbound test runs were undertaken using both the tanker and container ship. Inbound runs began in the ocean and transited the Bar Channel, the Anegado Channel, and the Army Terminal Channel. The proposed channel inbound tanker turned at the end of the run, while the existing condition tanker did not. The container ships, existing and proposed, continued into the Puerto Nuevo Channel. Outbound tankers exited the harbor by transiting the Army Terminal Channel, the Anegado Channel, and the Bar Channel. Existing condition tankers turned at the start of the outbound run. Container ships sailed by turning from the Puerto Nuevo Channel into the Graving Dock Channel and heading to sea through the Anegado and Bar channels.

Tests were conducted in a random order. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they might really be.

During each run, the characteristic parameters of the ship were automatically recorded every 5 seconds. These parameters included the position of the ship's center of gravity, speed, rpm of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

4 Study Results

A total of six professional pilots from the San Juan Harbor Pilots Association conducted simulator tests for San Juan Harbor.

Test Results, Week 1

Real-time testing of the San Juan Harbor simulation was conducted 12-29 September 1992 at the WES ship/tow simulator. During each simulation run, the pilot had full control over the vessel's rudder and engines and the actions of the assist tugs. While one pilot conned the vessel, the other acted as the ship's helmsman, steering the vessel and responding to the pilot's helm and engine orders. Upon completion of the first week of testing, the results were examined and adjustments were made to the proposed channels. Therefore, the results of the first week of testing will be presented prior to and separately from the remainder of the test results. Track plots of the first week of real-time testing conducted at the WES ship/tow simulator are presented in Plates 1-52.

Track Plot Analysis

Existing Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the existing channel are shown in Plates 1-4. These results are an accurate representation of the operating procedures the pilots presently employ. The pilots used the ranges to stay in the center of the Bar Channel until the turn into Anegado Channel. Observation of the track plot reveals that the vessels were set to the west side of the Bar Channel by the wind and wave conditions. After the vessel made the turn, the vessel's momentum carried the ship to the southern half of the channel. One of the vessels remained near the center of the channel after the turn, while the other came within a beam (125 ft) of the southern edge. Once the vessel stopped swinging, the pilots then steered the ship toward Anegado buoy "13". This was done to reduce the angle of the turn into Army Terminal Channel. Both vessels left the channel near "13", but were in no danger of grounding the vessel. After completing the turn into Army Terminal, both ships came near the eastern channel edge across from Army Terminal buoy "4". This is a scour area (and a shoal area

on the west side of the channel), and the uneven bank effects forced the tanker toward the scour area. The runs were ended when the vessel was in a position to begin docking. Although one of the tankers left the channel across from "7", the vessel did not ground.

Plan 1 Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the proposed Plan 1 channel are shown in Plates 5-8. These two ships navigated the Bar Channel and turned into the Anegado Channel in a manner very similar to ships transiting the existing channel. After finishing the turn into Anegado, the vessel remained near the center of the channel in order to utilize the widener between Anegado "14" and Army Terminal "2". One of the vessels slightly left the channel after making the turn. One of the runs was ended prior to turning the vessel because of time constraints. However, the Army Terminal Turning Area is identical for Plans 1 and 2 and three successful runs had already been recorded for this maneuver. The other vessel's run continued until it cleared the Army Terminal Dock and was in a position to begin docking.

Plan 2 Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the proposed Plan 2 channel are shown in Plates 9-12. These two ships navigated the Bar Channel and turned into the Anegado Channel in a manner very similar to ships transiting the existing channel and the Plan 1 channel. It should be noted that both ships are skewed relative to the channel while entering the channel from the ocean. This is because the Plan 2 Bar Channel alignment caused the northeastern waves to hit the ship at a steeper angle than either the existing or Plan 1 channels. However, in order to increase safety when boarding a ship under heavy wave conditions, the pilots will have the ship turn to be broadside of the waves in order to protect the pilot boat from wave action when alongside the lee of the ship. Once aboard the ship, the pilot then has to maneuver the ship back onto the ranges. The Plan 2 Bar Channel alignment will require less maneuvering for the ship to get on range after the pilot has boarded and provides adequate room for the pilots to compensate for the wave action. The pilots also noted that presently, their vision from the Bar Channel into the Anegado Channel is somewhat obscured by El Morro and the surrounding bluffs. The Plan 2 alignment allowed them to see further into the Anegado Channel from the Bar Channel, thus allowing them more time to react to other traffic such as ships, barges, pleasure craft, etc. In addition, the pilots noted that the ranges are easier to see in Plan 2 since the rear range is not obscured by the background.

In preparation for turning into the Army Terminal Channel, one of the two tankers left the channel near Anegado "13". This ship, drafting 36 ft, would have grounded. The other vessel remained to the west of "13", but hit Army Terminal Buoy "3" and would have also grounded. After transiting the Army Terminal Channel, both ships turned in the Army Terminal Turning Area and prepared to dock.

Existing Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the existing channel are shown in Plates 13-16.

These results are similar to those of the existing condition inbound tankers. Note that the container ships stayed on the western side of the Bar Channel, whereas the tankers remained on the center line. This is caused by keeping the vessel on a "straight course" while overcoming the drift tendency.

After turning into the Anegado Channel, the container ships (as did the tankers) steered towards Anegado buoy "13". One of the vessels left the channel near Army Terminal buoy "3", but did not hit the buoy and did not ground with a draft of 32 ft. Although both vessels entered the Army Terminal Channel on the east side, they were on the west side of the channel at the end of the reach. This was done to give the ship a better approach angle into Puerto Nuevo. Both pilots used port rudder to counteract the wind throughout the Army Terminal Channel. One of the ships left the channel across from Army Terminal Buoy "7", but would not have grounded. Both ships left the channel near Puerto Nuevo buoy "1" and one left the channel after passing the second docked vessel. These would have resulted in groundings.

Plan 1 Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the Plan 1 channel are shown in Plates 17-20. These runs were conducted without any adverse incidents such as grounding or hitting a channel marker. One vessel did come close to the channel edge near Anegado buoy "8", but did not leave the channel. Both ships transited the Anegado Channel on the western side in order to take advantage of the bend widener at the turn into the Army Terminal Channel. Both container ships remained slightly west of the center line of Army Terminal Channel and successfully turned into Puerto Nuevo.

Plan 2 Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the Plan 2 channel are shown in Plates 21-24. These runs were conducted without any adverse incidents although one vessel came extremely close to the channel edge near Army Terminal buoy "3". Note that one vessel in the ocean north of the entrance to the Bar Channel is skewed to port. This is because the pilot was unaware that the run had started and did quickly issue orders to counter the wave and wind action. The pilot recovered and asked to continue the run rather than start over.

Existing Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the existing channel are shown in Plates 25-28. Both of the vessels left the authorized channel while turning prior to sailing, but were in no danger of grounding because they were in ballast drafting 26 ft. One of the ships clipped the channel edge across from Army Terminal buoy "6" but was also in no danger of grounding. One of the tankers left the channel on the port side after passing Bar Channel buoy "1". This was a deliberate action. The pilot stated that under these conditions, he would use this maneuver to get the ship into position for safe disembarking.

Plan 1 Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the Plan 1 channel are shown in Plates 29-32. These runs were conducted without any adverse incidents.

Plan 2 Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the Plan 2 channel are shown in Plates 33-36. The only adverse action that occurred during these tests was when one of the tankers hit Army Terminal buoy "7". This was one of the pilot's early runs and he stated that he maneuvered toward the buoy expecting a stronger set due to wind. When he did not experience the set he expected, he hit the buoy.

Existing Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the existing channel are shown in Plates 37-40. These results are an accurate representation of the operating procedures the pilots presently employ. Included in these operating procedures is the practice of cutting across a portion of Anchorage Area E when turning from the Graving Dock Channel into the Anegado Channel.

Plan 1 Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the proposed Plan 1 channel are shown in Plates 41-44. Only one adverse incident occurred during one of these runs when the container ship left the authorized channel on the south side across from Puerto Nuevo buoy "7".

Plan 2 Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the proposed Plan 2 channel are shown in Plates 45-48. These runs were conducted without any adverse incidents.

Toward the end of the first week of testing, the pilots alerted WES to the fact that it is not uncommon (two or three times a week) for a small ship or tow to be docked perpendicular to the container docks along Puerto Nuevo. These ships are roll-on/roll-off Mediterranean vessels less than 300 ft long. When this occurs, the pilots bring inbound container ships from the Anegado Channel into the Graving Dock Channel, turn them in the Puerto Nuevo Turning Area, and back them into Puerto Nuevo. The Plan 2 turn between Puerto Nuevo and Graving Dock Channel does not allow any room for this maneuver. Preliminary analysis of the tests conducted in the Plan 1 turn between Puerto Nuevo and Graving Channel, as well as comments made by the pilots, indicate that the Plan 1 turn allowed more room than was needed. A representative from the Jacksonville District was present at this point in the test program and it was agreed that this should be addressed.

In order to determine an appropriate size for the turning area, an additional run was made with an inbound container ship in the Plan 1 channel. However, as opposed to earlier runs, the pilot brought the vessel down Graving Dock Channel, turned in the Puerto Nuevo Turning Area, and began to back into Puerto Nuevo. This run is shown in Plates 49-52. The run was stopped when everyone present agreed that the area required for turning had been defined. This turning area is shown in Figure 7 and replaces the Puerto Nuevo Turning Area in both Plan 1 and Plan 2 channels.

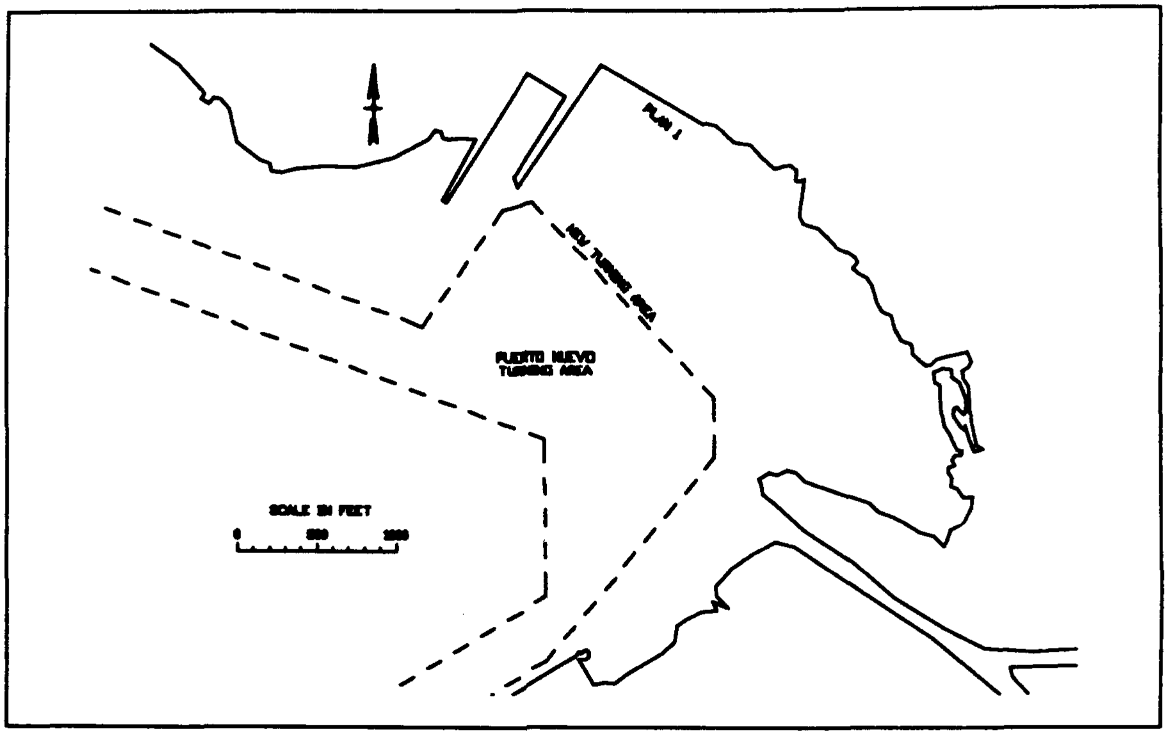


Figure 7. Puerto Nuevo Turning Area

Statistical Analysis

During each run, the control, positioning, and orientation parameters of the ship were recorded every 5 seconds. These parameters included position, speed, rpm of the propeller, rudder angle, and rate of turn. These statistical parameters are plotted against distance along track. The distance along track is calculated by projecting the position of the ship's center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line (Figures 8 and 9). For reference purposes, the locations of important landmarks are identified.

For all parameters the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section length was used. This means that for each individual run, each parameter was averaged over 500 ft. These means were then averaged over all runs under a given condition, thus a mean of the means.

Inbound Tankers, Clearance. Statistical analysis of inbound tanker clearance is shown in Plate 53. These results show that runs in the existing and Plan 2 channels averaged either a zero or negative port clearance as they approached buoy "13". Runs in the existing channel averaged a negative clearance toward the end of the Army Terminal Channel.

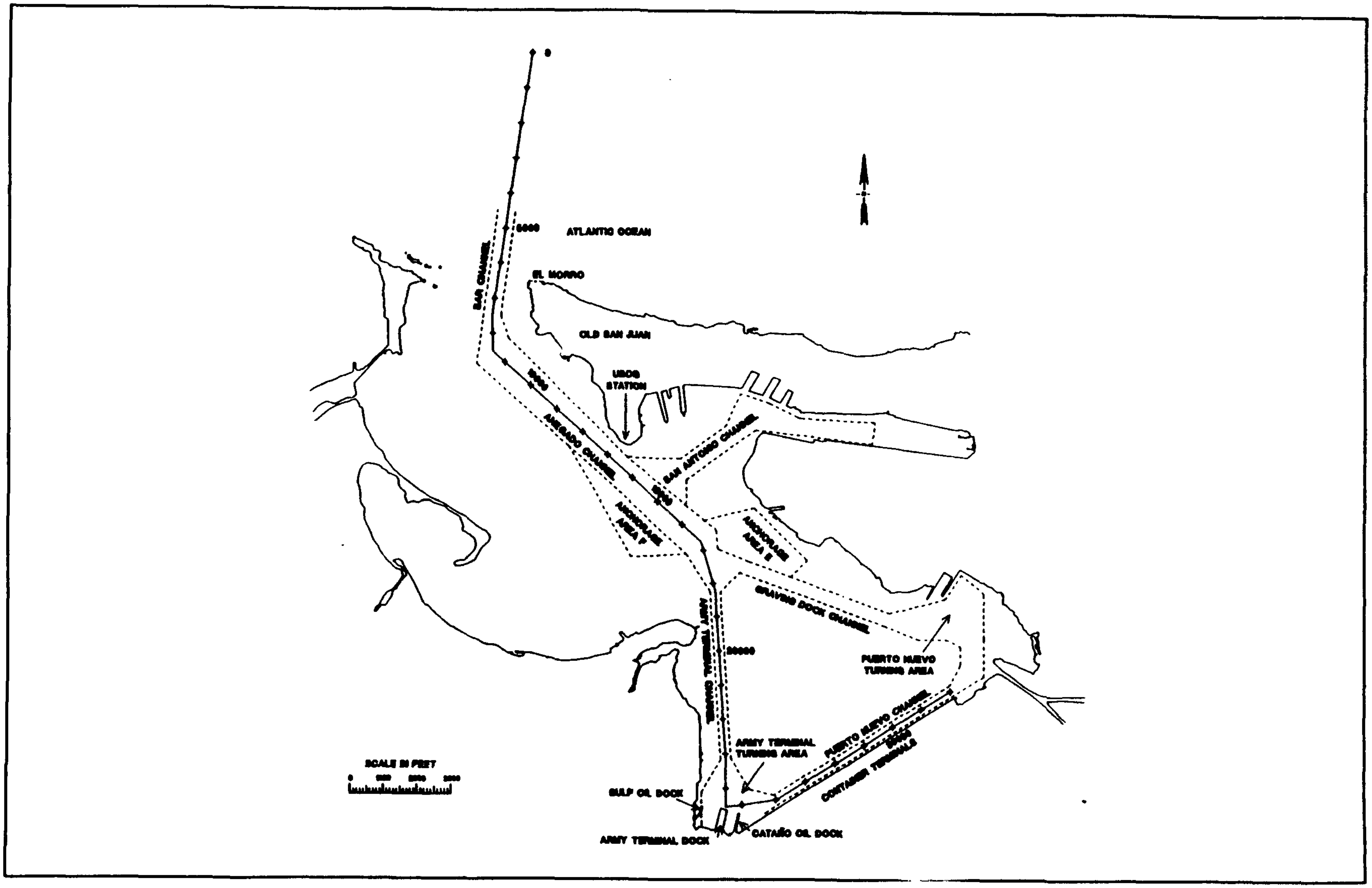


Figure 8. Distance traveled (Army Terminal Channel route)

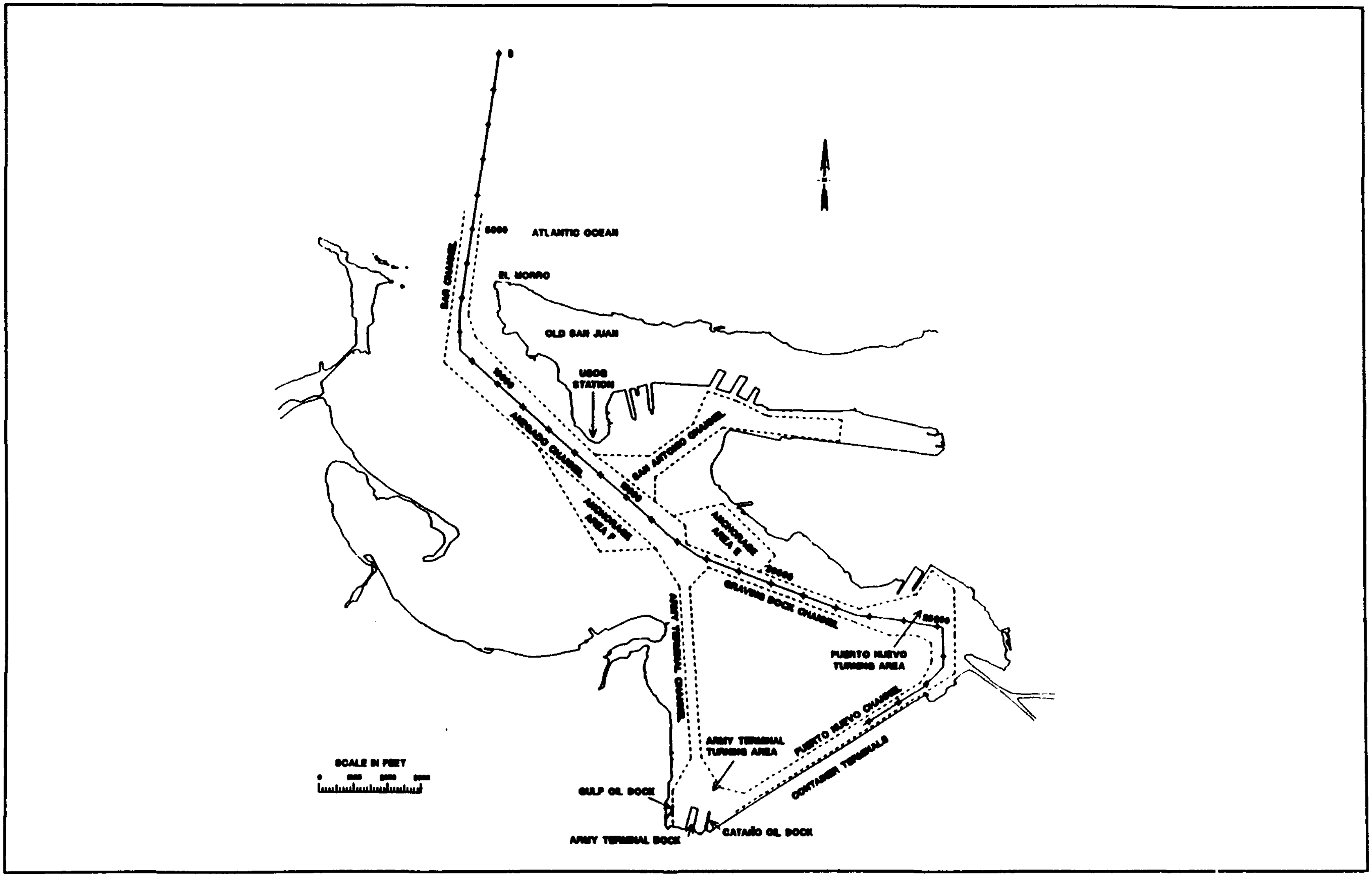


Figure 9. Distance traveled (Graving Dock Channel route)

Inbound Tankers, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by inbound tankers is shown in Plate 54. While in the ocean, Plan 2 runs required more rudder than either Plan 1 or the existing channel. This is because the alignment of the Plan 2 channel is nearly perpendicular to the wave action. Plan 1 required the most rudder angle near the USCG Station. Plan 2 required more rudder angle entering the Army Terminal Channel, but required less rudder once inside the channel. The only significant difference in the engine speed used was when the pilots increased their rpm for Plan 2 vessels when entering the Army Terminal Channel.

Inbound Tankers, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by inbound tankers is shown in Plate 55. Other than reconfirming that Plan 2 vessels had a higher drift angle (or crab angle) in the ocean, there is no significant difference between the three channels for these parameters.

Inbound Container Ships, Clearance. Statistical analysis of inbound container ship clearance is shown in Plate 56. These results show that runs in the existing and Plan 2 channels averaged a very small port clearance as they approached buoy "13". Runs in the existing channel averaged a negative clearance toward the end of the Army Terminal Channel.

Inbound Container Ships, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by inbound container ships is shown in Plate 57. As with inbound tankers, Plan 2 runs required more rudder than either Plan 1 or the existing channel while in the ocean. The rudder angle required was similar for the remainder of the run. Engine rpm's remain higher at the entrance for Plan 2 due to the increased drift angle.

Inbound Container Ships, Speed and Drift Angle. There is no significant difference between the three channels for these parameters, shown in Plate 58.

Outbound Tankers, Clearance. Statistical analysis of outbound tankers clearance is shown in Plate 59. These results show that vessels turning in the existing Army Terminal Turning Area left the channel on both the port and starboard side. Both Plans 1 and 2 show the vessel starting the run with a negative port clearance. This is because they began the run near the dock and does not show a grounding.

Outbound Tankers, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by outbound tankers is shown in Plate 60. The tanker transiting the Plan 2 channel required more rudder to turn into the Anegado Channel from the Army Terminal Channel. There were no other areas of significant differences in rudder angle or engine speed.

Outbound Tankers, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by outbound tankers is shown in Plate 61.

There is no significant difference between the three channels for these parameters.

Outbound Container Ships, Clearance. Statistical analysis of outbound container ship clearance is shown in Plate 62. These results show that Plan 2 vessels had a zero starboard clearance while turning from the Puerto Nuevo Channel into the Puerto Nuevo Turning Area. Existing channel runs had a negative starboard clearance turning from the Graving Dock Channel into the Anegado Channel.

Outbound Container Ships, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by outbound container ships is shown in Plate 63. Vessels operating in all three channels used similar rudder commands. However, ships in the existing channel required "full ahead" while turning into the Graving Dock Channel.

Outbound Container Ships, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by outbound container ships is shown in Plate 64. There is no significant difference between the three channels for these parameters.

Test Program and Proposed Channel Modifications

Channel Modifications

It was agreed to make the following modifications to Plans 1 and 2:

a. The Army Terminal Turning Area could be reduced in two locations: between buoys "4" and "6"; and between buoys "7" and 9".

b. The Plan 2 width of 350 ft for the Army Terminal Channel and the Puerto Nuevo Channel was adequate for safe navigation. Accordingly, the Plan 1 width of 450 ft was reduced to 350 ft for both channels.

c. The Plan 2 turn between the Anegado Channel and the Army Terminal Channel was modified such that Anegado buoy "14" remained in its present location, Army Terminal buoy "2" was moved to the Plan 1 location, and Army Terminal buoy "3" was moved so that it was gated with "2". This modification was done to test an alternative turn widener on both sides of the turn to produce a funnel effect. These new alternative channels, Plan 1A and Plan 2A, are shown in Figures 10 and 11, respectively.

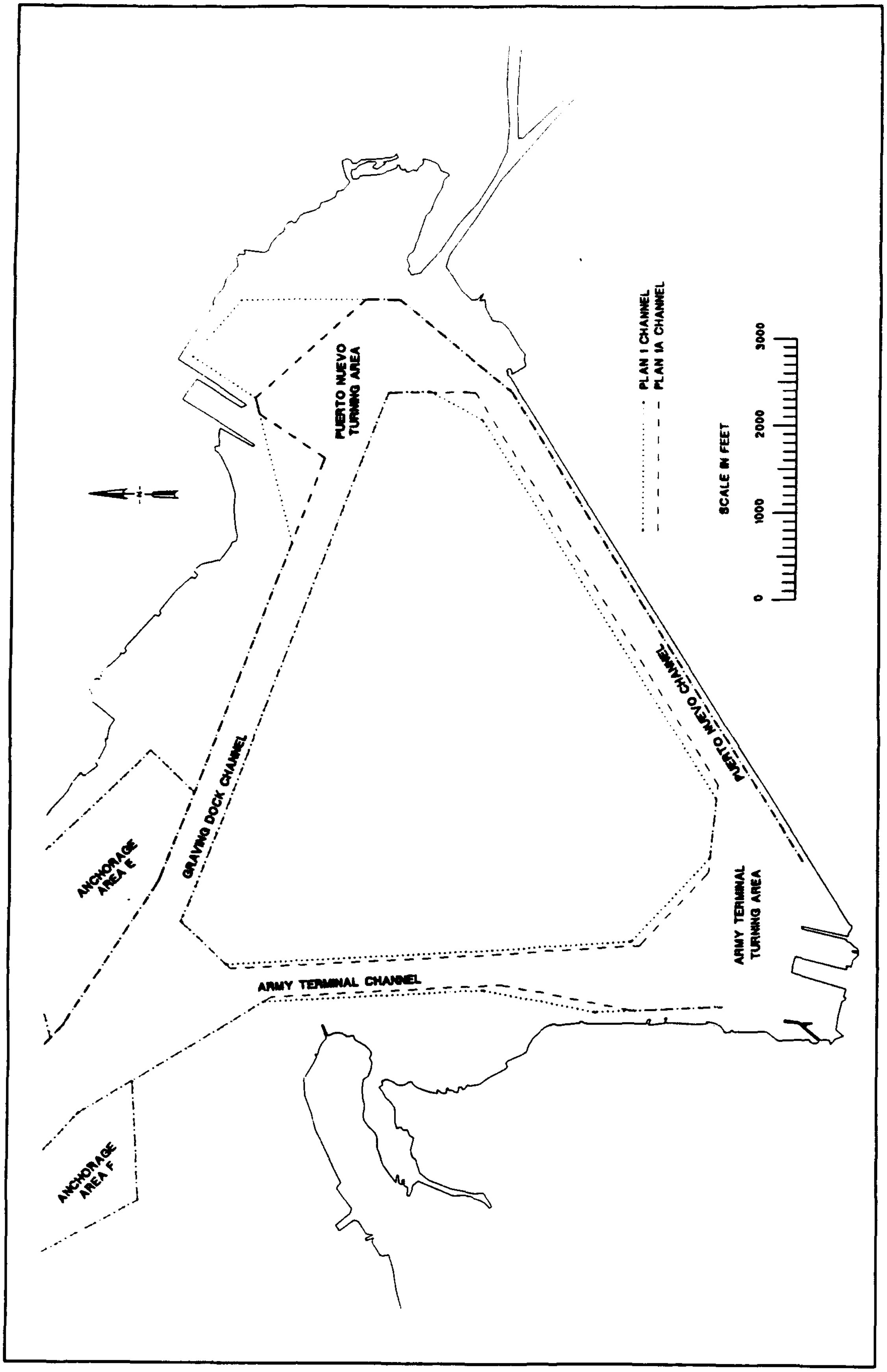


Figure 10. Plan 1A channel configuration

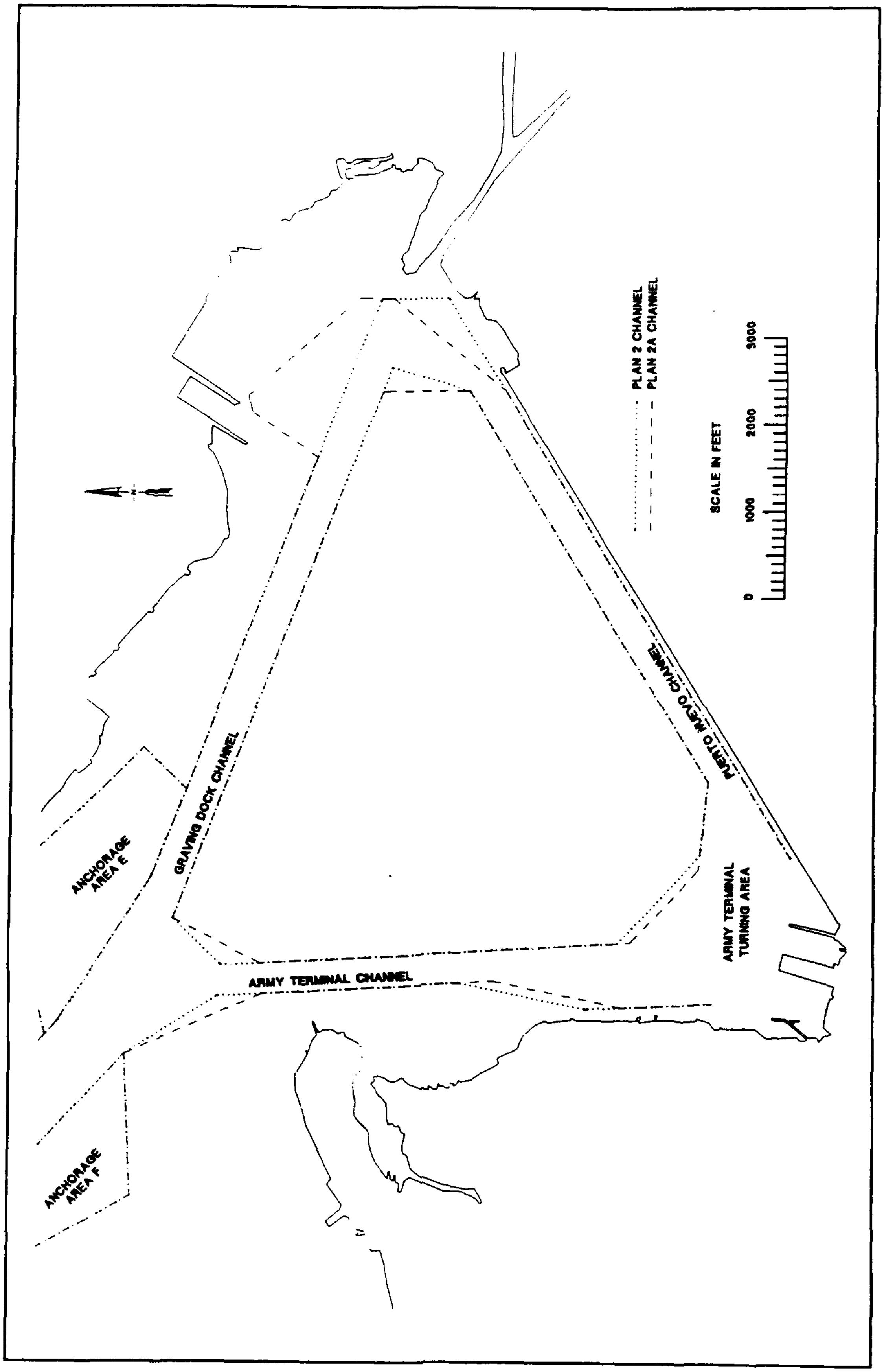


Figure 11. Plan 2A channel configuration

Test Program Modifications

It was agreed that an additional scenario would be added to the test program to test container ships backing into Puerto Nuevo using the turning area shown in Figure 7. This was to be a short run beginning in the Graving Dock Channel with the initial position, heading, and speed to be determined from the test run used to design the new turning area.

In order to best utilize the time available during the remainder of the test program, the following changes were made.

Inbound runs transiting the Plan 2A channel were stopped once the ship completed the turn into Army Terminal Channel. Since the Plan 1A and 2A Army Terminal Turning Areas were identical, completing the run would have been redundant.

Runs undertaken to test inbound container ships turning in the Puerto Nuevo Turning Area were begun with the vessel already in the Graving Dock Channel. The exception to this is Plan 2A, where the run began in the Atlantic Ocean. The reason for complete runs for the Plan 2A channel was to test the effect of moving Anegado buoy "13" west for ships entering Graving Dock Channel from Anegado.

Outbound container ships transiting the Plan 2A channel were started near the end of the Graving Dock Channel. This was done because the Plan 1A and 2A Puerto Nuevo Turning Areas were identical.

Test Results, Weeks 2 and 3

Track Plot Analysis

The results of the second and third week of testing are presented in Plates 65-120.

Existing Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the existing channel are shown in Plates 65-68. These track plots show that these pilots did not bring the ship as close to Anegado buoy "13" as did the first group of pilots. This caused two of the runs to hit Army Terminal buoy "3". There were several incidents of ships leaving the authorized Army Terminal Channel: between buoys "3" and "5", near buoy "6", near buoy "7", and just north of the Gulf Oil Dock. There were no instances of ships leaving the Bar Channel and the Anegado Channel (other than at the turn into Army Terminal).

Plan 1A Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the Plan 1A channel are shown in Plates 69-72. As in the existing channel, the ships transited the Bar Channel and the Anegado Channel prior to

the turn into Army Terminal Channel without incident. While making the turn, two ships left the channel near buoy "3", the same as in the existing condition. Once the turn was made, the track plots in the Plan 1A Army Terminal Channel show some improvement over the existing channel, with only one ship leaving the authorized channel north of buoy "7". With the exception of one, all ships turned successfully in the Army Terminal Turning Area. One ship was going too fast to stop, and hit the Army Terminal Dock.

Plan 2A Conditions, Inbound, Tanker. Track plots of inbound tankers transiting the Plan 2A channel are shown in Plates 73-76. These track plots show, as did those from the first week of testing, that vessels entering the realigned Bar Channel experienced more of a set due to wind and wave action. However, none of the runs came close to the edge of the Bar Channel or the Anegado Channel. One vessel failed to make the turn into Army Terminal and went aground east of Army Terminal buoy "3". Note that this ship was on the west side of Anegado Channel near buoy "14" and therefore out of position to make the turn. After the run the pilot stated that he had misinterpreted the new buoy locations and was unable to recover from his mistake. The remainder of the vessels were able to remain in the center of the channel after making the turn from Anegado Channel into Army Terminal Channel. This shows an improvement from both the existing and Plan 1A channels.

Existing Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the existing channel are shown in Plates 77-80. One of the ships clipped the edge of the Bar Channel south of buoy "2". However, the vessel would not have grounded as there is deep water in this area. None of the vessels left the Anegado Channel, but one ship, just after making the turn from Anegado Channel, left the Army Terminal Channel south of buoy "3". While turning west in preparation to turn into Puerto Nuevo, one ship left the Army Terminal Channel across from buoy "7". Two of the ships hit the dock while turning into Puerto Nuevo. This has occurred in real life as evidenced by the hull-shaped notches in the dock. The one ship that did complete the turn into Puerto Nuevo slightly left the Puerto Nuevo Channel on the northern side.

Plan 1A Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the Plan 1A channel are shown in Plates 81-84. All of these vessels successfully transited the Bar Channel. One ship left the Anegado Channel and crossed over into the San Antonio Channel by about 20 ft. One ship failed to remain in the channel after turning into Army Terminal Channel and hit Army Terminal buoy "3". All ships successfully turned into the Puerto Nuevo Channel.

Plan 2A Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the Plan 2A channel are shown in Plates 85-88. These track plots show that none of the vessels left the Bar Channel but one vessel clipped the edge of the San Antonio Channel. Three of the four ships successfully turned into the Army Terminal Channel, while one hit buoy "3" and left the channel on the east side. The spacing of the ship icons (plotted

every 10 seconds) shows that this vessel was traveling significantly faster than the other three ships. The pilot of this vessel asked to continue his run past the turn into Puerto Nuevo and did so effectively.

Puerto Nuevo Turning Area Track Plot Analysis

As previously stated, a series of tests was added to the program for the final 2 weeks of testing to evaluate the proposed Puerto Nuevo Turning Area. The pilots had an extremely difficult time performing this maneuver on the simulator. This was due apparently to the lack of peripheral vision on the simulator's projec 1 visual image. Although they were also provided with a radar image of the area, the pilots found the display confusing because of the high number of aids to navigation. There are presently eight channel markers and two front ranges in the area.

Existing Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the existing channel are shown in Plates 89-90. The ships left the channel at numerous places during the turn. Only two runs were conducted for this condition.

Plan 2A Conditions, Inbound, Container Ship. Track plots of inbound container ships transiting the Plan 2A channel are shown in Plates 91-94. These plots show no problems for vessels turning from Anegado into Graving Dock. As in the existing condition, the ships left the channel at numerous places during the turn. One run was stopped with the ship east of buoy "10". The vessel ended up in this position because the pilot mistook the radar image of the front range towers as buoys.

Plan 3 Conditions, Inbound, Container Ship. In order to address the problems encountered while testing the Puerto Nuevo Turning Area, an additional proposed turning area, Plan 3 (Figure 12), was developed during the final week of testing. Track plots of inbound container ships turning in the Plan 3 Puerto Nuevo Turning Area are shown in Plates 95 and 96. Although the vessels left the channel boundaries, the results show an improvement over the Plan 2A turning area. The pilots felt that any problems associated with this maneuver were due to visual limitations on the simulator.

Existing Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the existing channel are shown in Plates 97-100. One of the tankers hit Army Terminal buoy "9" while turning. Both ships clipped the edge of the channel across from Army Terminal buoy "7", but neither would have grounded because the ships were in ballast. Neither ship had any difficulties with the remainder of the run.

Plan 1A Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the Plan 1A channel are shown in Plates 101-104. All runs were successful.

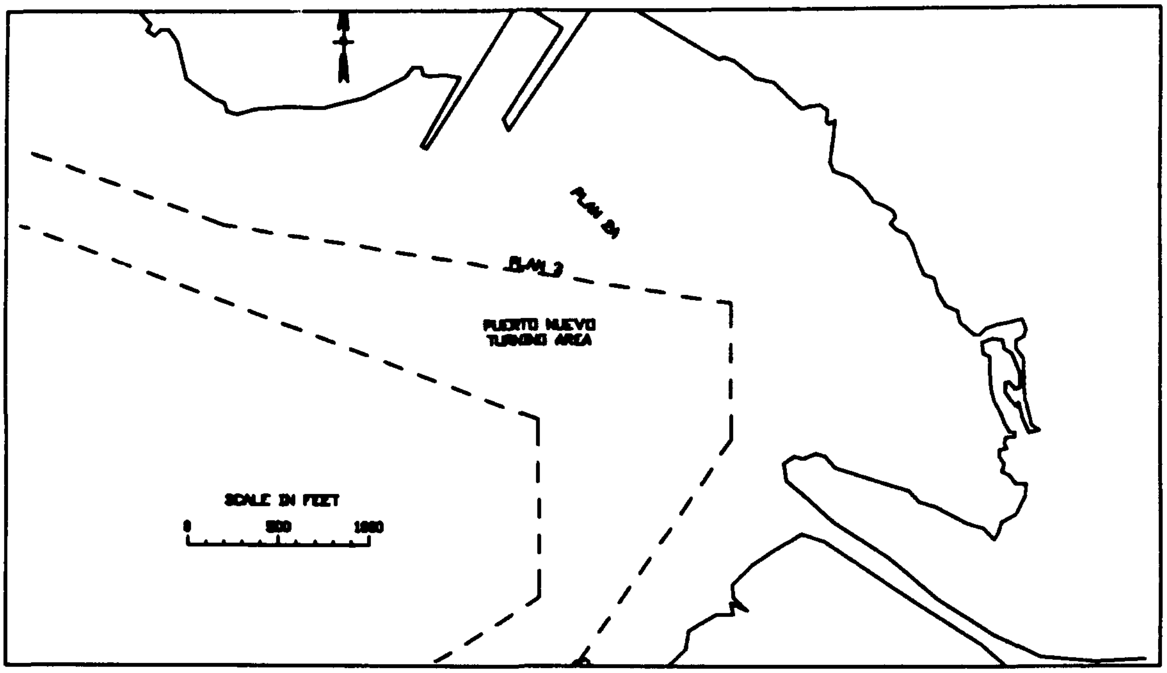


Figure 12. Plan 3 Puerto Nuevo Turning Area

Plan 2A Conditions, Outbound, Tanker. Track plots of outbound tankers transiting the Plan 2A channel are shown in Plates 105-108. All runs were successful.

Existing Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the existing channel are shown in Plates 109-112. One of the ships went north into the Puerto Nuevo Turning Area. This was due to a miscommunication between the pilot and the tug operator. The ship left the Graving Dock Channel on the south side while recovering. As in the runs conducted in week 1 under the same conditions, the vessels cut across a portion of Anchorage Area E when turning from the Graving Dock Channel into the Anegado Channel. These ships transited the Anegado Channel and the Bar Channel without incident.

Plan 1A Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the Plan 1A channel are shown in Plates 113-116. Several of the ships left the channel on the south side while leaving the Puerto Nuevo channel. There were no other adverse incidents for the remainder of the runs.

Plan 2A Conditions, Outbound, Container Ship. Track plots of outbound container ships transiting the Plan 2A channel are shown in Plates 117-120. None of the ships left the channel or experienced any difficulties during these runs.

Statistical Analysis, Weeks 2-3

Inbound Tankers, Clearance. Statistical analysis of inbound tankers clearance is shown in Plate 121. These results show that runs in the existing and Plan 1A channels averaged a negative port clearance as they turned into the Army Terminal Channel. Runs in the Plan 2A channel had a zero clearance at this point. However, as previously discussed, one pilot had misinterpreted the new buoy locations and was unable to recover. The track plot, Plate 76, clearly shows that the remainder of the runs were in the center of the channel.

Inbound Tankers, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by inbound tankers is shown in Plate 122. While in the ocean, Plan 2A runs required more rudder than either Plan 1A or the existing channel. This is because the alignment of the Plan 2 channel is nearly perpendicular to the wave action. Plans 1A and 2A required more rudder angle near the USCG Station than did the existing channel.

Inbound Tankers, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by inbound tankers is shown in Plate 123. Other than reconfirming that Plan 2A vessels had a higher drift angle (or crab angle) in the ocean, there is no significant difference between the three channels for these parameters.

Inbound Container Ships, Clearance. Statistical analysis of inbound container ship clearance is shown in Plate 124. These results show that runs in the existing channel had zero starboard clearance and a negative port clearance in the Army Terminal Turning Area.

Inbound Container Ships, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by inbound tankers is shown in Plate 125. While in the ocean, Plan 2A runs required more rudder than either Plan 1A or the existing channel. This is because the alignment of the Plan 2A channel is nearly perpendicular to the wave action. Plan 2A required opposite rudder and less engine speed than the existing or Plan 1A channels between the USCG Station and the Army Terminal Channel.

Inbound Container Ships, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by inbound container ships is shown in Plate 126. Other than reconfirming that Plan 2 vessels had a higher drift angle (or crab angle) in the ocean, there is no significant difference between the three channels for these parameters.

Outbound Tankers, Clearance. Statistical analysis of outbound tankers clearance is shown in Plate 127. These results show that vessels turning in the existing Army Terminal Turning Area left the channel on both the port and starboard sides.

Outbound Tankers, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by outbound tankers is shown in Plate 128. The rudder angle used in all three channels is similar. Both Plans 1A and 2A required less engine speed than did the existing condition, which ran full ahead for most of the run.

Outbound Tankers, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by outbound tankers is shown in Plate 129. Plan 2A had about 2 knots higher speed from the USCG Station to El Morro, reflecting the pilots' confidence in making the smaller angle turn.

Outbound Container Ships, Clearance. Statistical analysis of outbound container ship clearance is shown in Plate 130. These results show Plan 1A vessels having negative starboard clearance in the Puerto Nuevo Turning Area. Existing channel runs had a negative starboard clearance turning from the Graving Dock Channel into the Anegado Channel.

Outbound Container Ships, Rudder Angle and Engine Speed. Statistical analysis of the rudder angle and engine speed used by outbound container ships is shown in Plate 131. Vessels operating in all three channels used similar rudder commands. Vessels transiting the existing and Plan 1A Graving Dock Channel used more rpm than did the Plan 2A ships.

Outbound Container Ships, Speed and Drift Angle. Statistical analysis of the ship speed and drift angle used by outbound container ships is shown in Plate 132. There is no significant difference between the three channels for these parameters.

Pilots' Ratings

To determine what the pilots thought about the proposed channel improvements, after each run they were asked to complete a questionnaire rating each channel segment and turn on a scale from 0 to 10. Higher ratings indicate a more difficult run. The pilots were instructed to rate each segment such that if the maneuver was just as difficult as they would expect in real life, that maneuver would be rated a five. The results of this survey are shown as an average of all responses for a given conditions. The average ratings for the existing channel include all six pilots. Plans 1 and 1A, 2 and 2A are identical for the Entrance Channel, the Anegado Channel, and the turn between them. Therefore, the ratings for these segments include all six pilots. The remainder of the Plans 1 and 2 ratings include only the last two groups of pilots.

Inbound Tanker. The average pilot ratings for the inbound tankers are shown in Figure 13. These ratings show that the pilots felt that both plans improved navigation of San Juan Harbor for inbound tankers. They also felt that the Plan 2A turn from Anegado into Army Terminal was slightly superior to the Plan 1A turn.

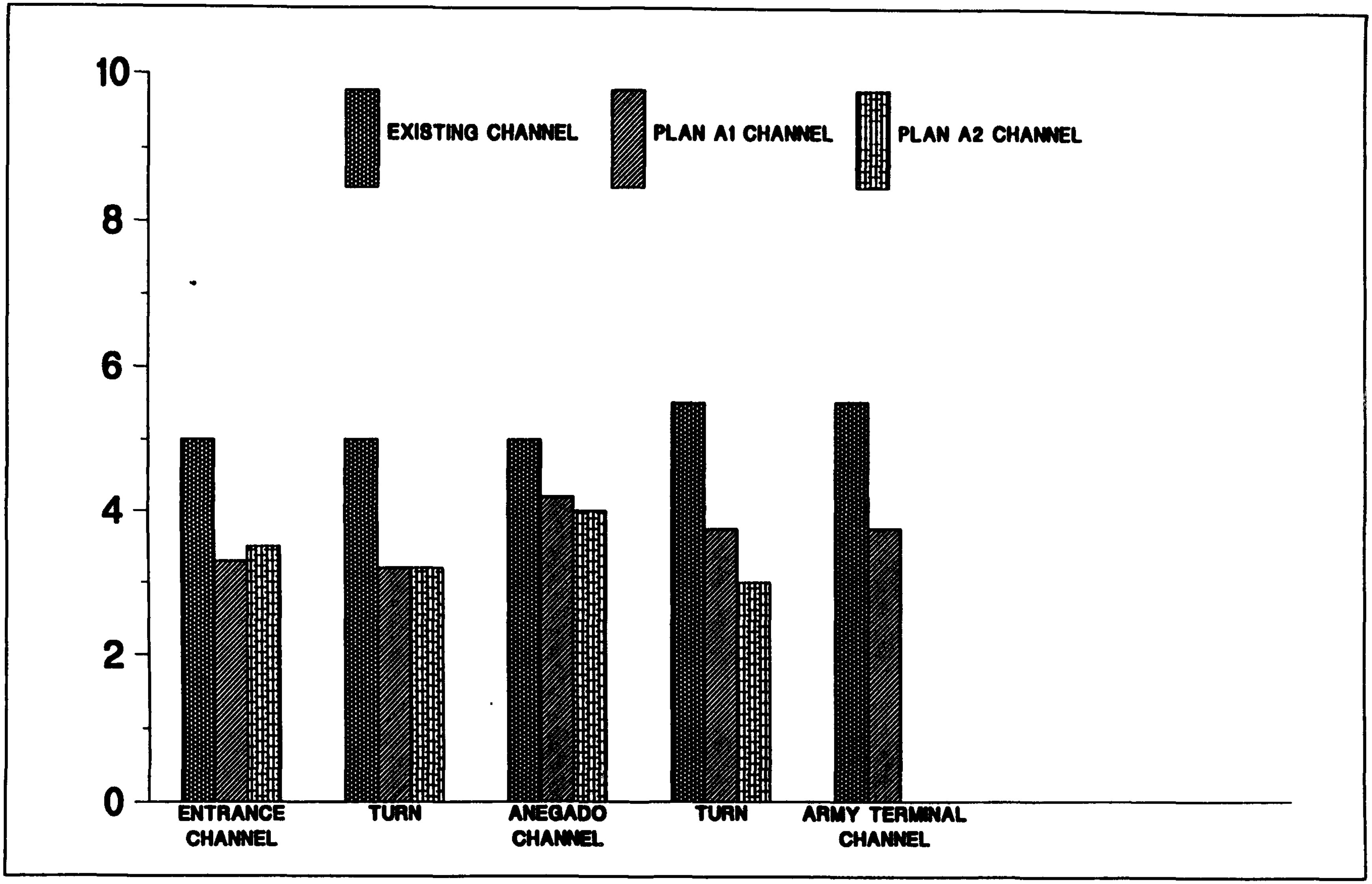


Figure 13. Pilot ratings, inbound tanker

Inbound Container Ship. The average pilot ratings for the inbound container ships are shown in Figure 14. These ratings are very similar to the ratings for inbound tankers and show that the pilots felt that both plans improved navigation of San Juan Harbor. They also felt that the Plan 2A turn from Anegado into Army Terminal was slightly superior to the Plan 1A turn.

Outbound Tanker. The average pilot ratings for the outbound tankers are shown in Figure 15. These ratings show that the pilots felt that both plans improved navigation of San Juan Harbor for outbound tankers. They also felt that the Plan 2A was slightly superior to the Plan 1A for the turn from Army Terminal into Anegado and Anegado Channel. They felt the Plan 1A was slightly superior to Plan 2A for the turn from Anegado into the Entrance Channel and for the Entrance Channel.

Outbound Container Ship. The average pilot ratings for the outbound tankers are shown in Figure 16. These ratings show that the pilots felt that both plans improved navigation of San Juan Harbor for outbound tankers. They also felt that the Plan 2A was slightly superior to the Plan 1A.

Final Questionnaire

After finishing all test runs, the pilots completed a final questionnaire to give their opinions on the project as well as on the simulation. Some of the comments made by the pilots on the project follow:

Which Plan, 1A or 2A, did you prefer for the Entrance Channel and turn into Anegado Channel?

"Plan 2. Approaching entrance more from the west gives navigators a better view of outbound traffic in Anegado Channel."

"Plan 2. Approaching from the west gives navigators a better view of outbound traffic in Anegado Channel. But also it is dangerous in the months of October until January due to weather conditions in those months. The eastward winds and the sea current affect the approach."

"Plan 2. Angle of approach in Plan 2 puts the ship at angle that permits pilot boarding in heavy weather. Visibility into channel is also improved. Easier turn and better visibility are great."

Which Plan, 1A or 2A, did you prefer for the turn from Anegado Channel into the Army Terminal Channel?

"Plan 1. Cut the west corner of Army Terminal Channel, doing this turn safer for vessel to stay on the red side of channel when entering this area."

"Plan 2. Buoys 3 & 2 should not be staggered."

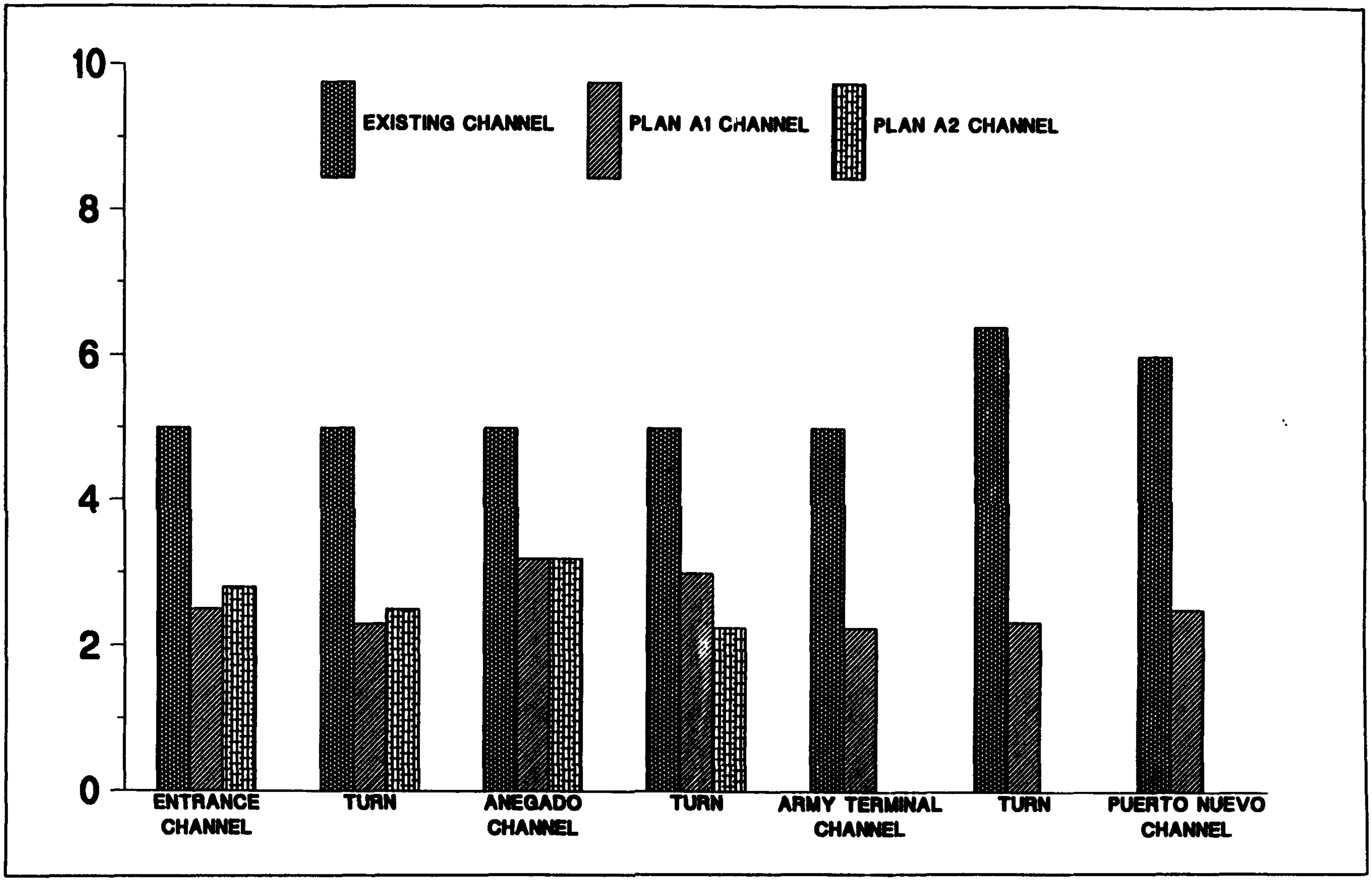


Figure 14. Pilot ratings, inbound container ship

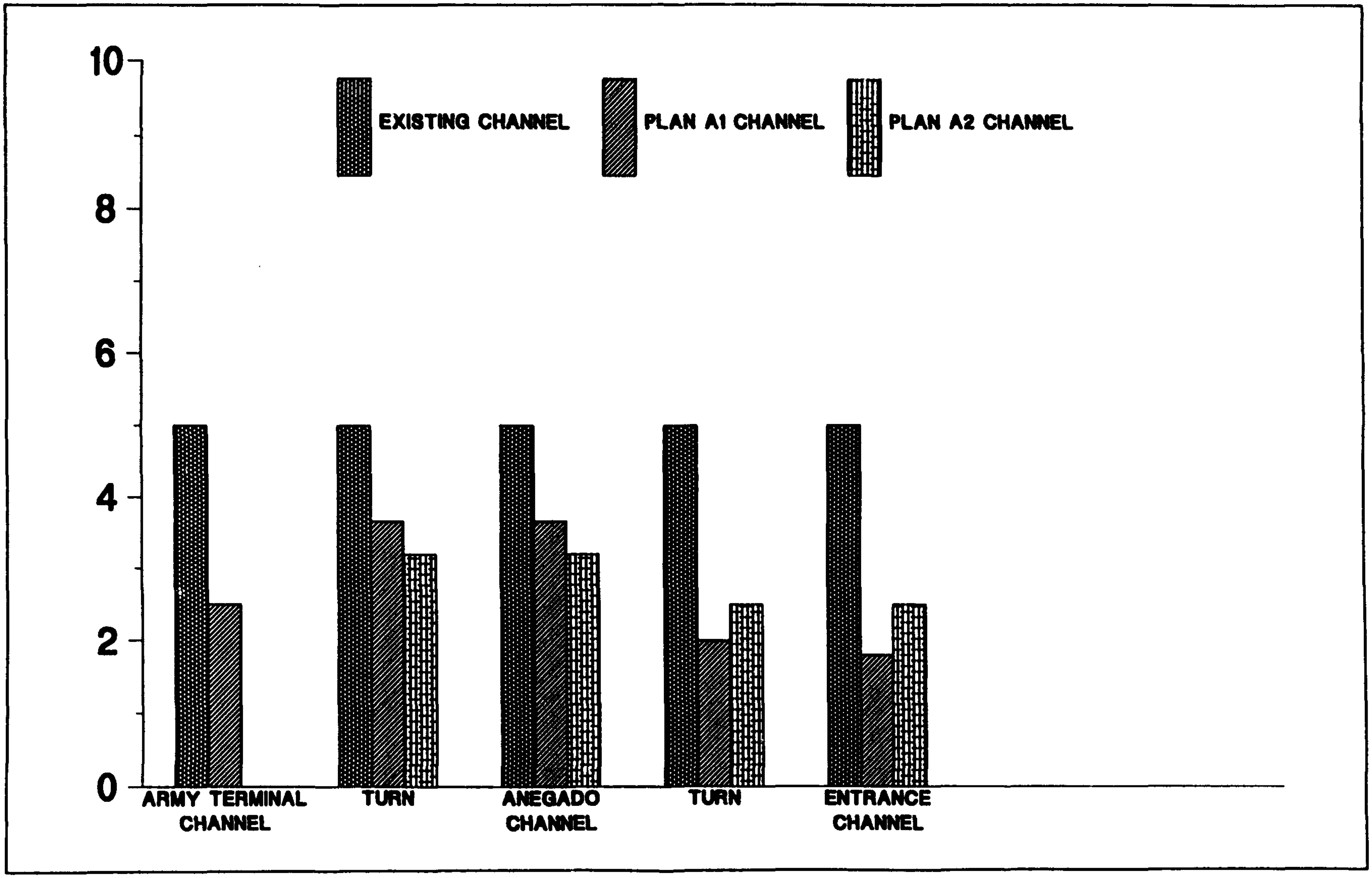


Figure 15. Pilot ratings, outbound tanker

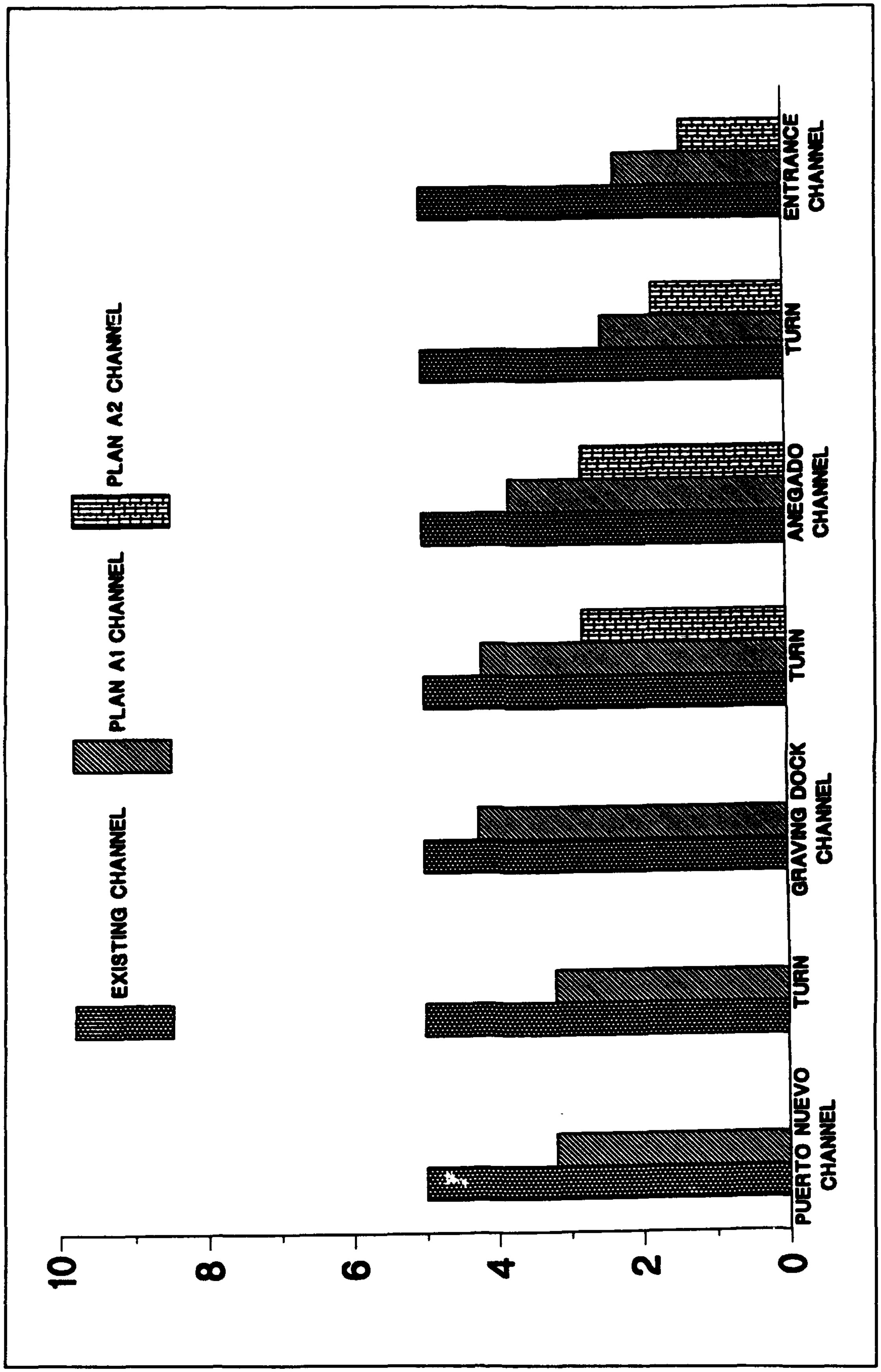


Figure 16. Pilot ratings, outbound container ship

What are your thoughts on the proposed Army Terminal Channel?

"The width of 350 ft is sufficient for the safe navigation of vessels using this channel."

What are your thoughts on the proposed turn from Army Terminal Channel to Puerto Nuevo Channel?

"Great - Generous"

"Cutting this corner is the most important part of the project."

What are your thoughts on the proposed Puerto Neuvo Channel?

"The width of 350 ft is sufficient for the safe navigation of vessels using this channel."

"The width of the channel past buoy 1 is not a great improvement considering the beam of the vessels, but is adequate."

What are your thoughts on the proposed turn from Puerto Nuevo into Graving Dock Channel?

"The southeast corner should be dredged as we used in the exercise." (Plan 3)

What are your thoughts on the proposed location of six mooring dolphins in Anchorage Area E [Figure 17]?

"Anchorage "E" is a small anchorage. At times depending on vessel's size, two vessels can be anchored in this area safely. With the proposed six mooring dolphins, I think only one vessel would be safely moored, as the other four dolphins and lack of maneuvering space would make it not safe to bring a second nor a third vessel into this area."

One pilot provided a sketch of an alternative design (Figure 18).

Fast-Time Analysis of Graving Dock

At the District's request, WES conducted an additional study of Graving Dock Channel after preliminary results had been furnished to the District. Simulation of the proposed deepening of Graving Dock Channel was run at the existing channel width of 400 ft. A fast-time study was undertaken to determine if a 350-ft-wide channel, the same width as Puerto Neuvo and Army Terminal channels, would be adequate. The proposed modified channel would be 350 ft for the proposed depth and centered within the existing 400-ft-width channel.

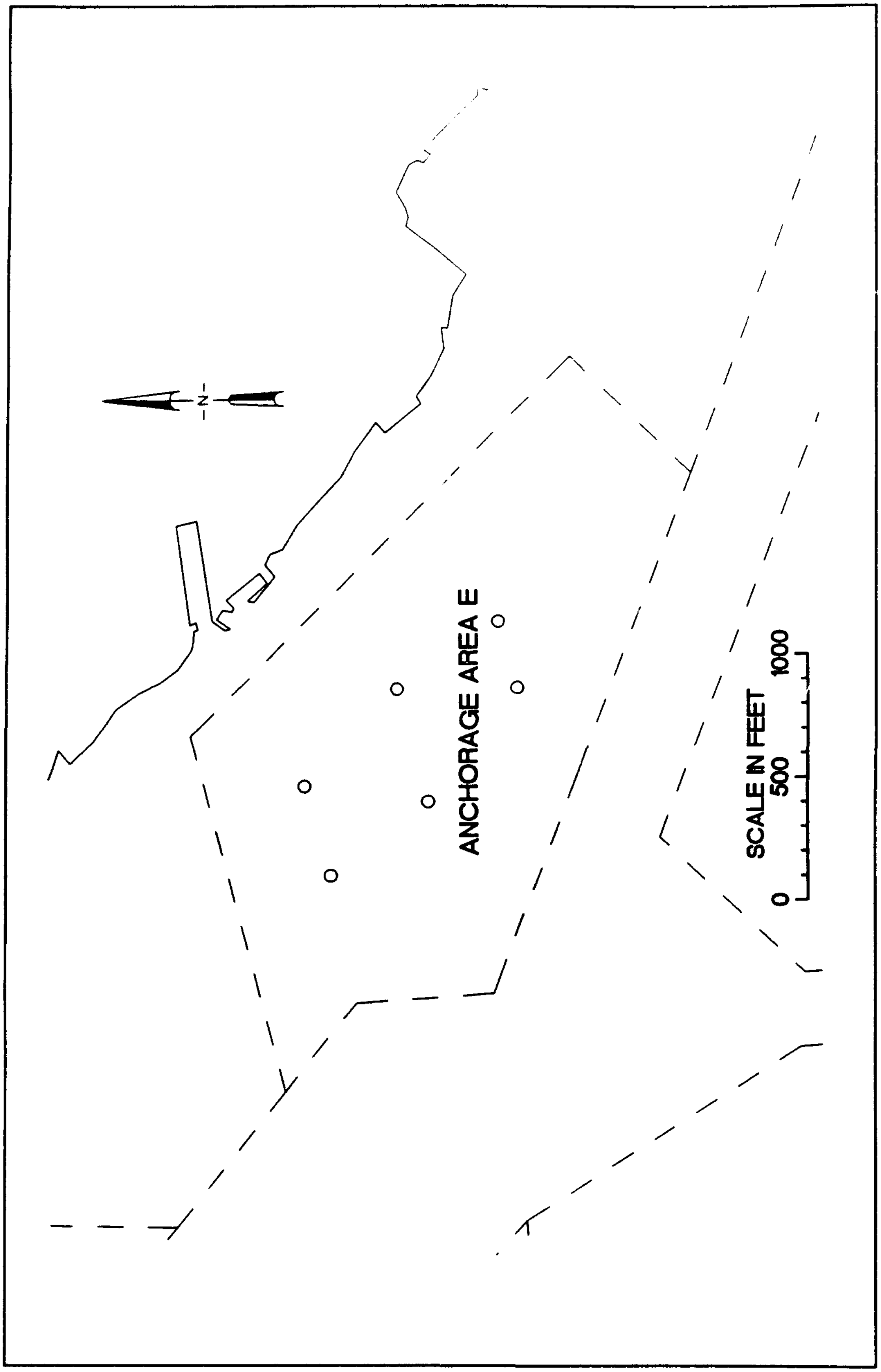


Figure 17. Mooring dolphins

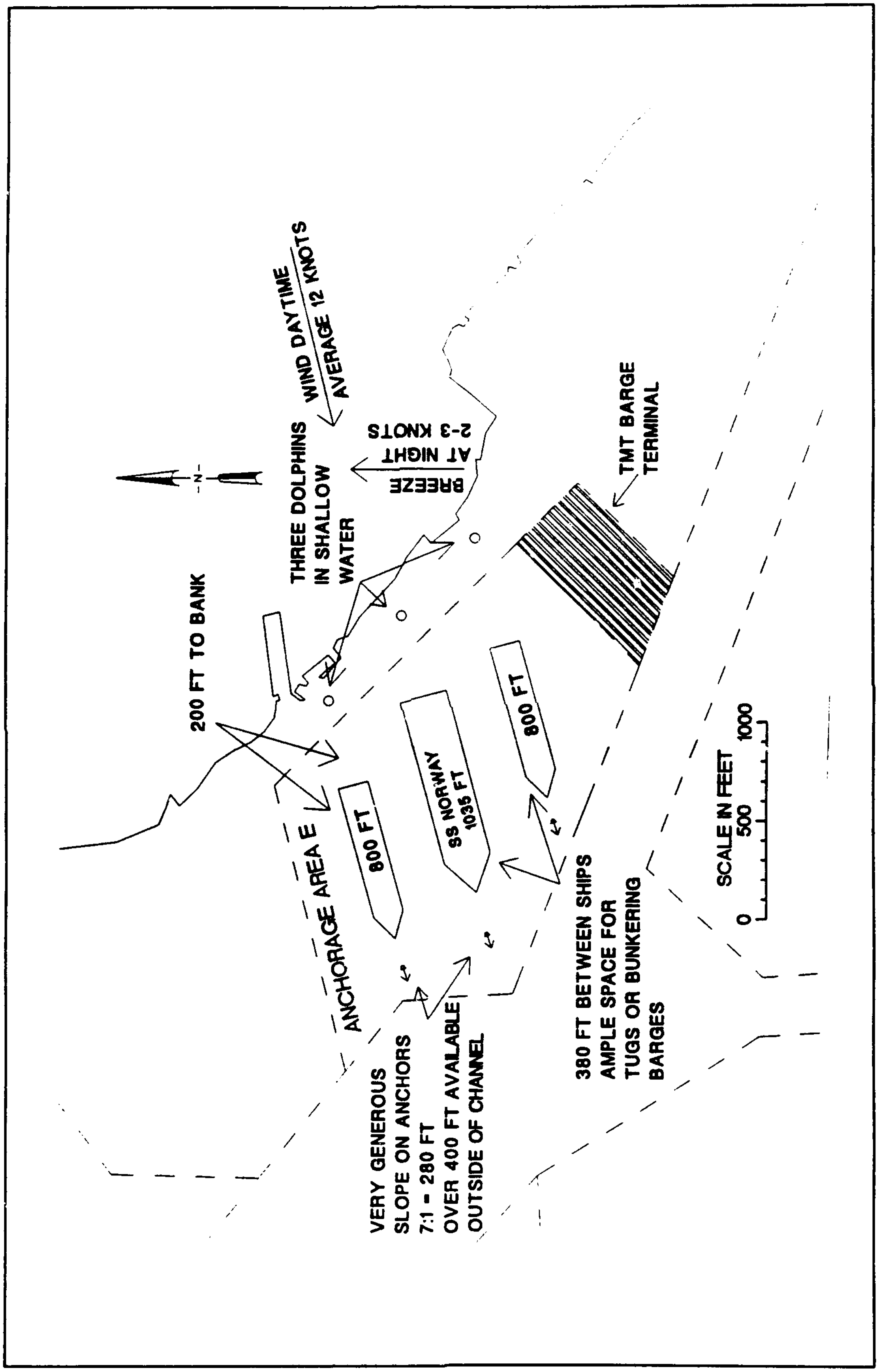


Figure 18. Mooring dolphins, alternative locations

Fast-time runs are pilotless tests wherein the simulated vessel attempts to follow a given path at set engine speeds for each leg of the path. Results from the fast-time analysis are presented for both inbound and outbound container ships in Plates 133-138. These track plots show the 350-ft-wide channel to be sufficient for the fast-time runs. However, it should be noted that the fast-time module might not operate a ship in the same manner as a pilot would.

5 Vertical Motion Study

Vessels transiting the Entrance Channel move vertically in response to wave action. A vertical motion study was contracted to a research naval architect in order to determine the depth required in the Entrance Channel. The study was conducted with both the tanker and containership vessels drafting 36 ft. The vessels transited the entrance, both inbound and outbound, at speeds of 10 and 15 knots for three wave conditions: severe, intermediate, and average. Each wave condition was tested for three combinations of wave height and period. This was done because the wave height and period decrease for each condition as the waves approach the harbor channels. The wave height/period combinations tested for each condition are described as follows:

Condition	Largest Wave		Medium Wave		Smallest Wave	
	Height ft	Period sec	Height ft	Period sec	Height ft	Period sec
Severe	15	15.5	10	12.8	5	11.2
Intermediate	10	12.5	7	11.5	3.2	10.3
Average	5.3	11.0	3	10.0	1.5	9.5

The vertical motion of the vessel was computed for both the 10- and 15-knot speeds. The bow and stern squat of both vessels in still water was computed for speeds of 10 and 15 knots as follows:

Vessel	Speed, knots	Bow Squat, ft	Stern Squat, ft
Container ship	10	1.38	0.82
Container ship	15	4.48	2.62
Tanker	10	3.03	1.85
Tanker	15	9.80	6.00

The sum of the vertical motion and the squat was used to define the underkeel clearance required. The channel depth was computed by adding the underkeel clearance required to the 36-ft draft of the vessel.

The results of that study are presented in Plates 139-156. The wave angle was measured from the bow along the longitudinal axis of the ship. Wave directions of 30, 45, and 60 degrees were used for outbound vessels, and wave directions of 120, 135, 0 and 150 were used for inbound vessels. For all instances, the vertical motion of the tanker was greater than that of the container ship operating in the same wave conditions. Because squat increases with ship speed, the vertical motion of either vessel traveling at 15 knots was significantly greater than the same vessel traveling at 10 knots. The tanker traveling at 15 knots was selected as the worst-case scenario, and the vertical motion for the wave heights shown in Figure 6 was used develop the Plan 1A and 2A stepped channels shown in Figures 19 and 20, respectively. Plots of the average speed of inbound tankers in the Entrance Channel are shown in Plates 55 and 123. These plots show the average ship speed in the Entrance Channel to be between 12 and 13 knots. The squat of these vessels is about 5 ft less than the same ships traveling at 15 knots. This difference will provide a factor of safety above the draft and ship motion.

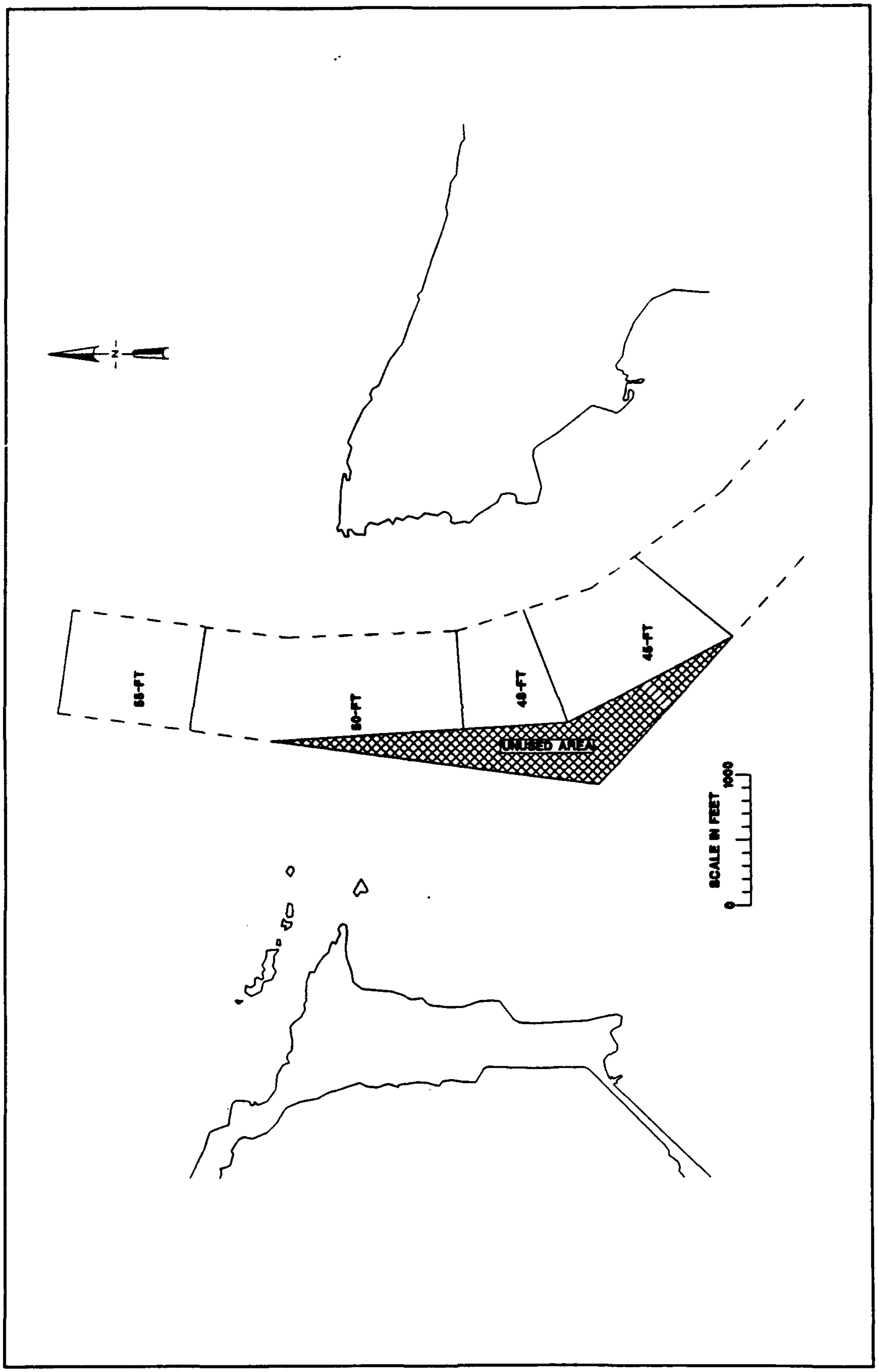


Figure 19. Plan 1, stepped channel

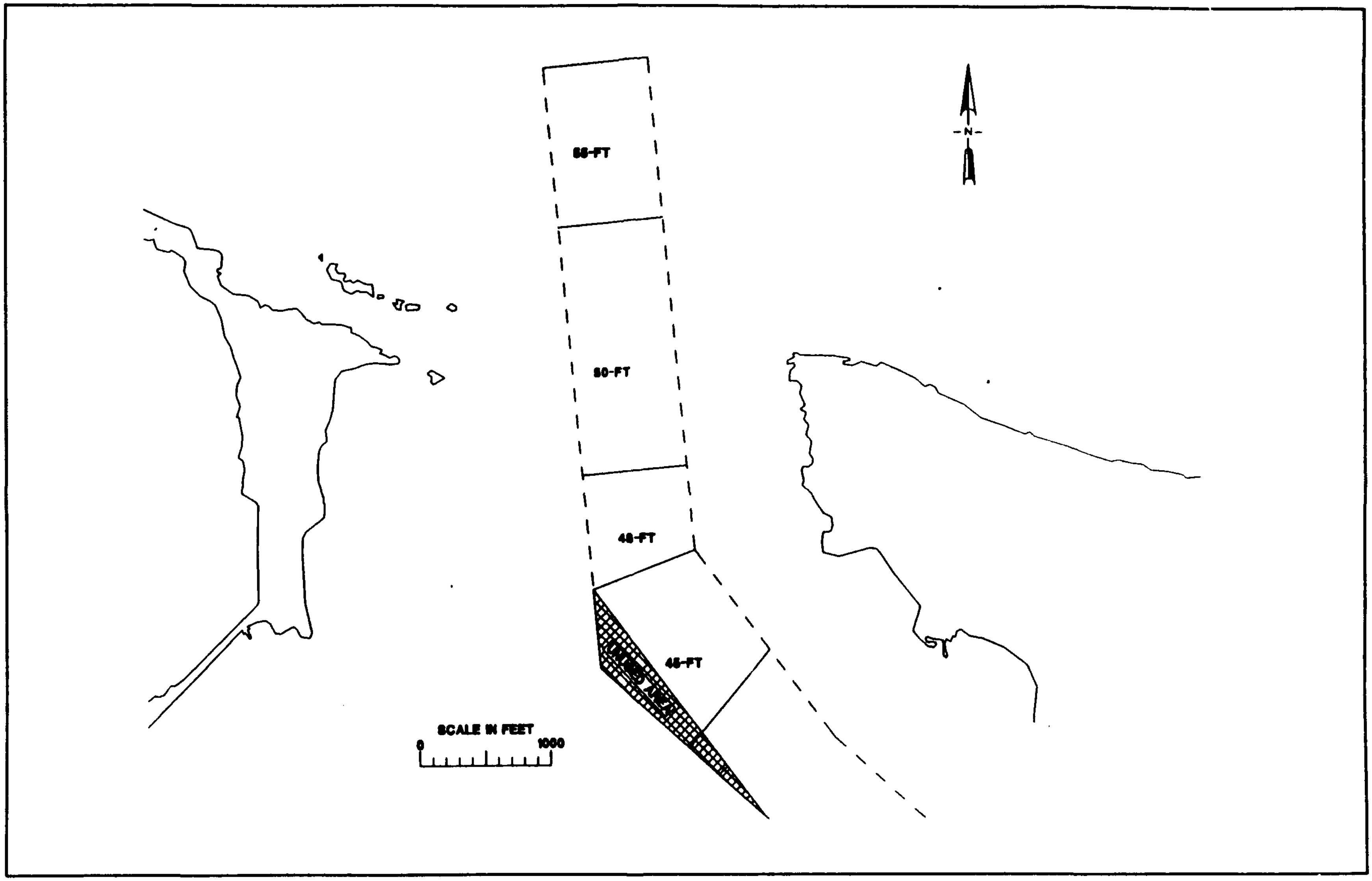


Figure 20. Plan 2, stepped channel

6 Conclusions and Recommendations

Based on the real-time ship simulator study conducted by WES, the following conclusions may be drawn:

a. Even with larger ships using the proposed channel, the proposed channel's layout and dimensions are generally safer than the existing channel's.

b. A reduced width (350 ft) from that proposed in the feasibility study for the Army Terminal, Puerto Nuevo, and Graving Dock Channels is safe.

c. Both proposed Bar Channel designs are safe with the additional width. The realigned channel (Plans 2 and 2A) has several advantages:

(1) Additional protection provided by the vessel alignment from waves during pilot boarding.

(2) Improved visibility of the ranges (which are obscured by a penninsula for the existing and Plan 1 alignment).

(3) Improved visibility of traffic in the Anegado Channel.

(4) Easing the turn between Anegado Channel and the Entrance Channel.

Realigning this entrance should significantly improve this turn, not only for piloted vessels, but especially for those that call without pilotage. Although ships transiting the Plan 2A channel were more influenced by the wind and wave conditions in the ocean, the reach was always succesfully transited, even under the adverse conditions tested.

d. The turn between Anegado and Army Terminal Channels is difficult and required additional design changes during the testing program to develop a safe arrangement.

e. The original turn between Army Terminal and Puerto Nuevo Channels was more than adequate and could be reduced in width slightly, as shown in Plans 1A and 2A.

f. The Graving Dock Channel is used for inbound container ships under some conditions and will require deepening and a redesign of the turn between the Puerto Nuevo and Graving Dock Channels if it is to be used by inbound deeper drafted container ships.

g. The limited testing performed on a redesign of the Puerto Nuevo Turning Area indicated an improved design but may require additional testing to finalize a safe and efficient layout.

Based on the real-time ship simulation study conducted at WES, the following recommendations are made:

a. Either the Plan 1A or 2A Bar Channel will provide safe navigation. However, for the reasons stated in subparagraph *c* of the preceding paragraph the Plan 2A Bar Channel layout and dimensions are recommended.

b. It is recommended that the area on the western side of the channel at the turn into Anegado Channel could be reduced for both plans as shown in Plates 157 and 158. Track plots of all runs conducted in the Plans 1 and 1A channels are shown in Plate 157 with the area not used shown with hatch marks. Track plots of all runs conducted in the Plans 2 and 2A channels are shown in Plate 158 with the area that could be reduced marked. Although one ship does slightly enter the Plan 2 area to be reduced, all ships had ample room and were under control. The Plan 2 channel flared to the west between Anegado buoys "8" and "4". The area hatched is an extension of the western Anegado channel edge south of buoy "8". Although the area between buoys "4" and "8" is the location of most of the historical vessel groundings, reducing the channel width in this area does not reduce safety. This is true for several reasons. First, the additional width in the Bar Channel, as well as the change in alignment for Plan 2, significantly eases the turn into Anegado Channel. Second, as one pilot during testing observed, any vessel that enters the hatched area is in a position that makes successfully negotiating the turn into Anegado Channel unlikely. Third, moving the channel markers to the redefined channel edges may actually improve safety by keeping ships away from the western side of the Bar Channel just north of the turn into Anegado Channel.

c. Based on the results of the vertical motion study for both Plans 1A and 2A, Entrance and Bar Channel depths as shown in Figures 19 and 20 are recommended.

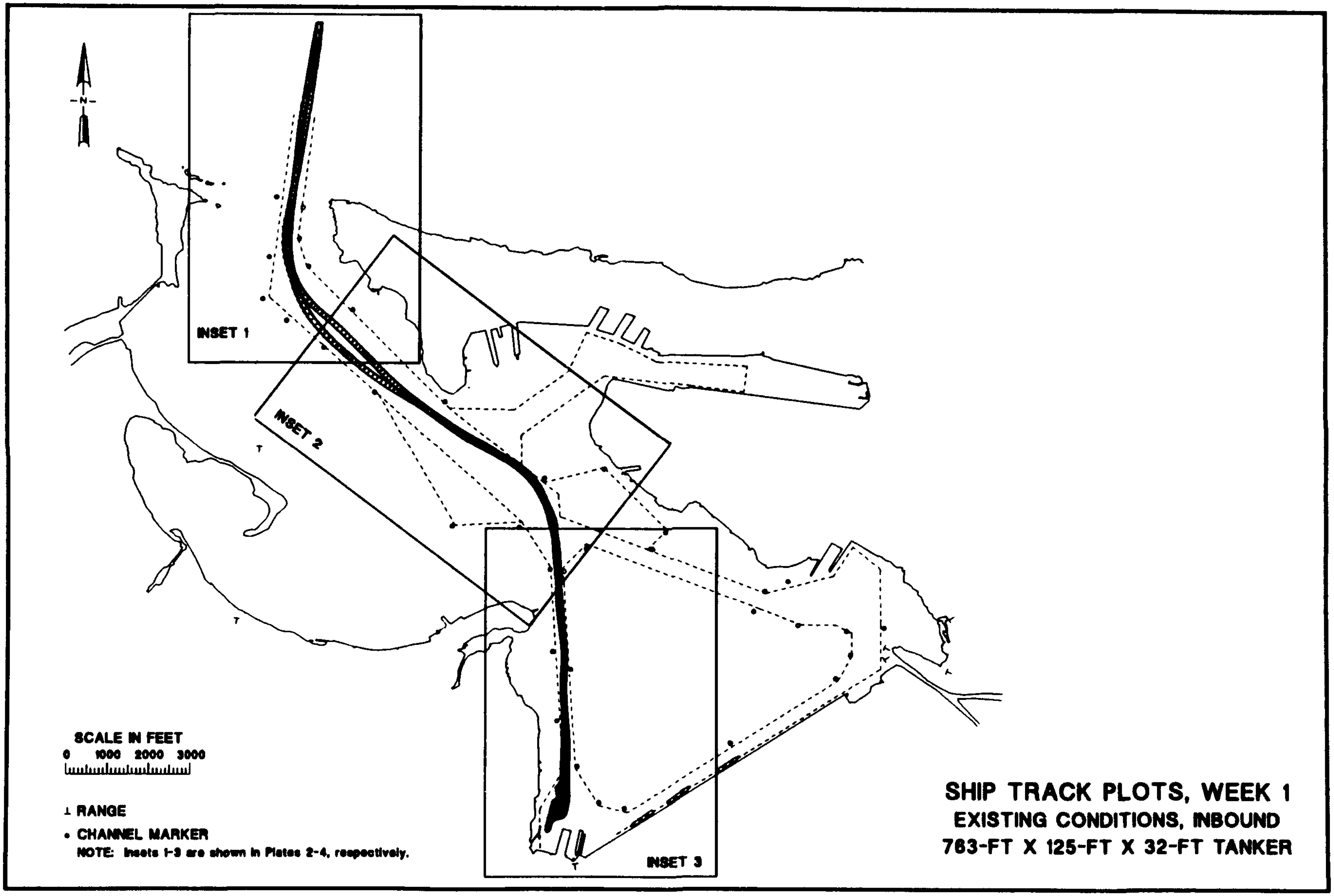
d. The Plan 2A turn between the Anegado Channel and the Army Terminal Channel is recommended.

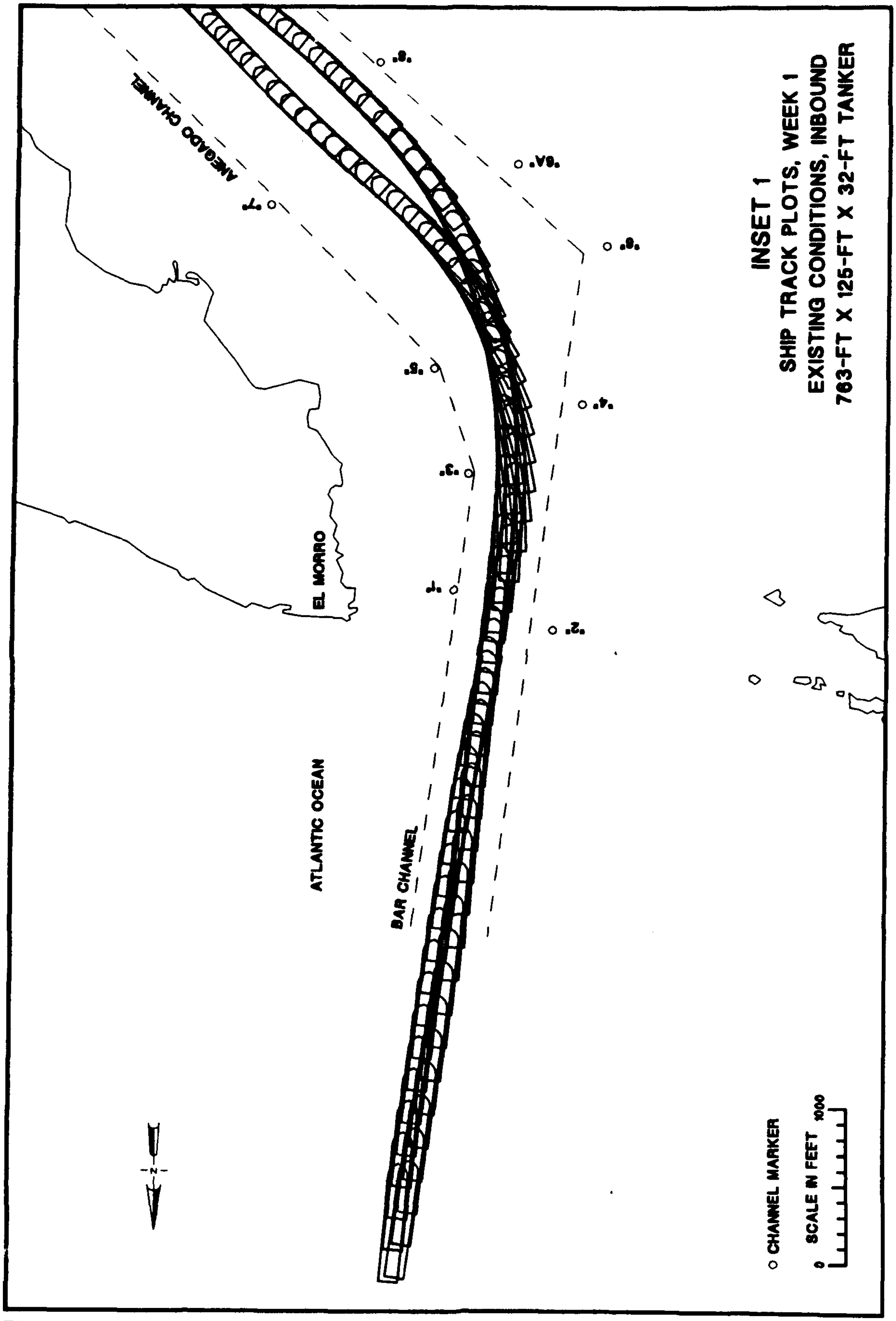
e. The 350-ft width with layouts as tested appears to be adequate for Army Terminal, Puerto Nuevo, and Graving Dock Channels and is therefore recommended.

f. The Army Terminal Turning Area as tested in the Plan 1A and 2A conditions is recommended.

g. The Plan 3 Puerto Nuevo Turning Area produced better results than any other plan tested. The pilots who tested this plan felt it was superior and any difficulties were simulator oriented. Therefore, the Plan 3 layout is recommended with the suggestion that additional tests be conducted before construction.

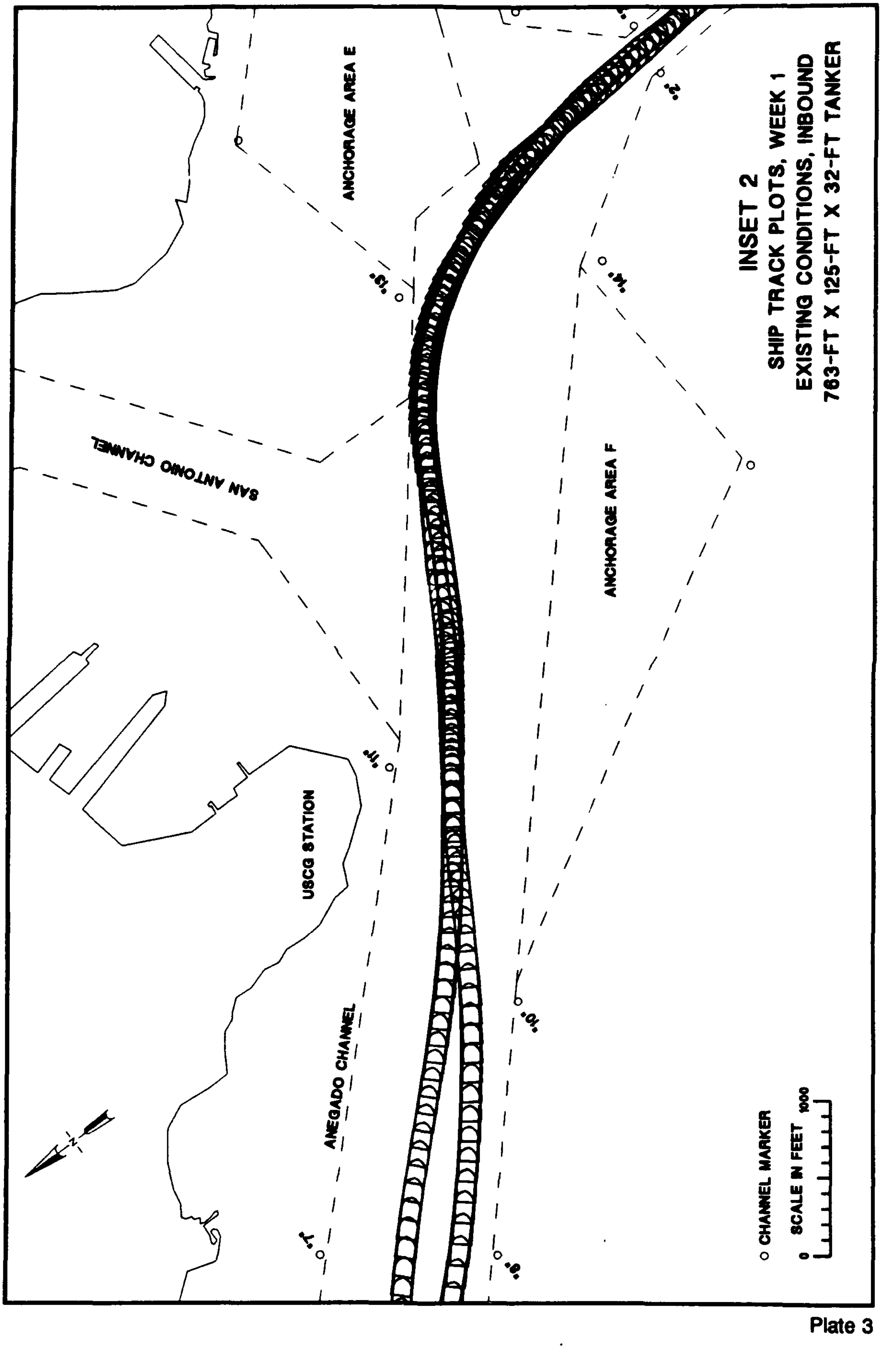
h. If traffic or operating situations warrant accommodating inbound loaded container ships entering the Graving Dock Channel due to vessels blocking the Puerto Nuevo Channel, the Graving Dock Channel should be deepened to the same depth as the Army Terminal and Puerto Nuevo Channels.

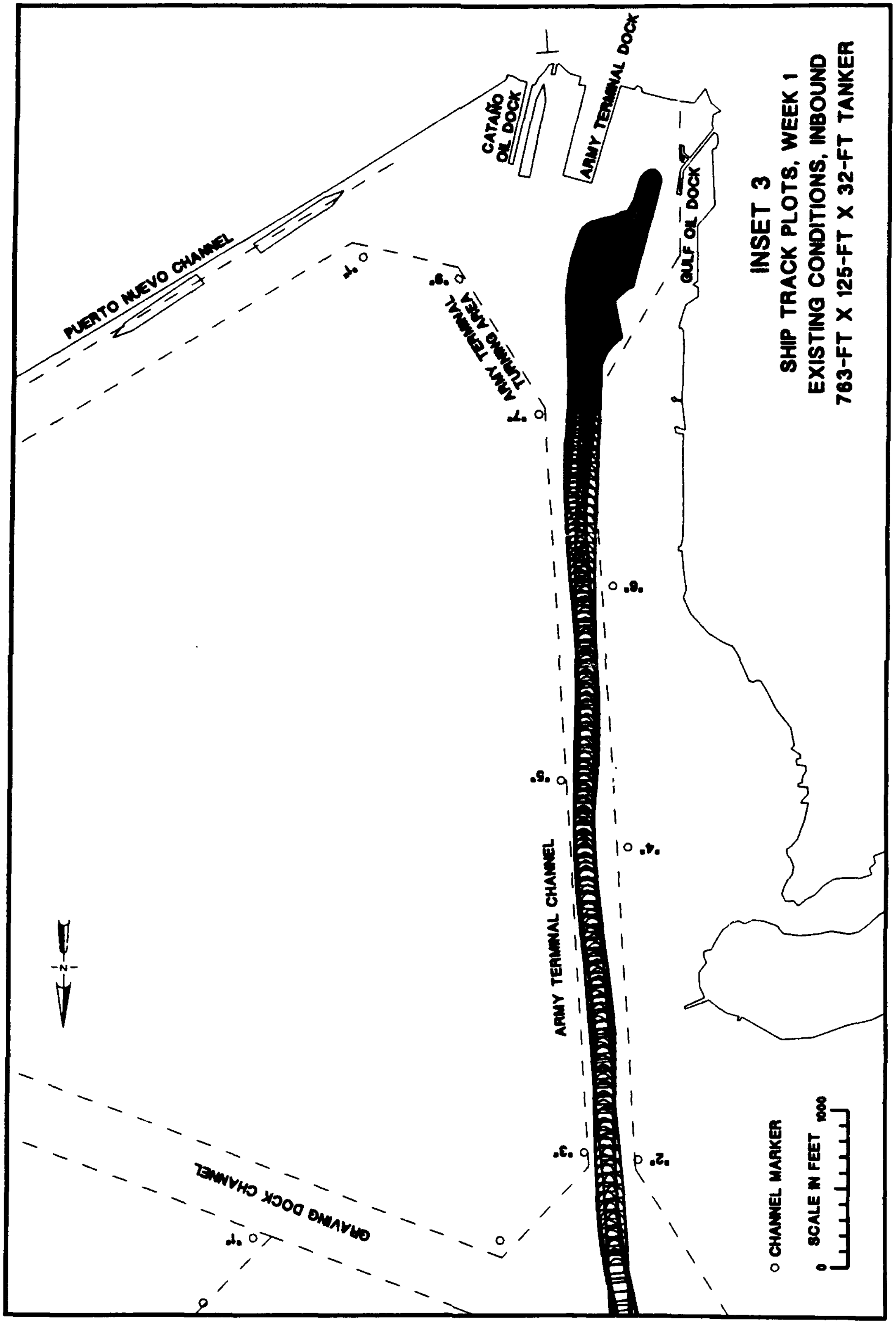

SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
INSET 1
INSET 2
INSET 3
N
SCALE IN FEET
0 1000 2000 3000
⊥ RANGE
• CHANNEL MARKER
NOTE: Insets 1-3 are shown in Plates 2-4, respectively.



INSET 1
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
"8"
"6A"
"6"
"7"
"5"
"4"
"3"
"1"
"2"
N
CHANNEL MARKER
SCALE IN FEET
0
1000

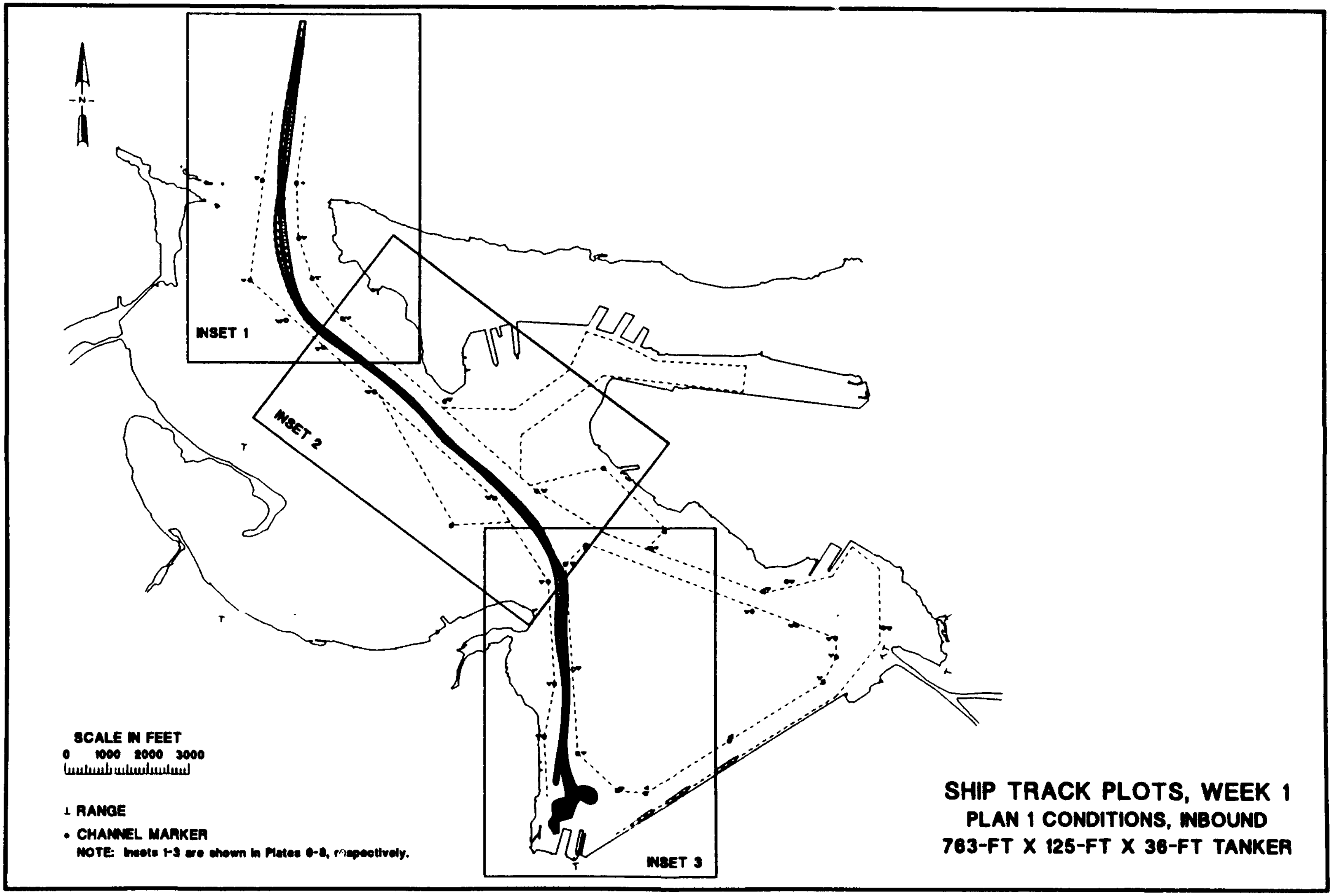
Plate 2


INSET 2
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000



INSET 3
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
PUERTO NUEVO CHANNEL
ARMY TERMINAL TURNING AREA
GULF OIL DOCK
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000
1
2
3
4
5
6
7
8
9

Plate 4



SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER

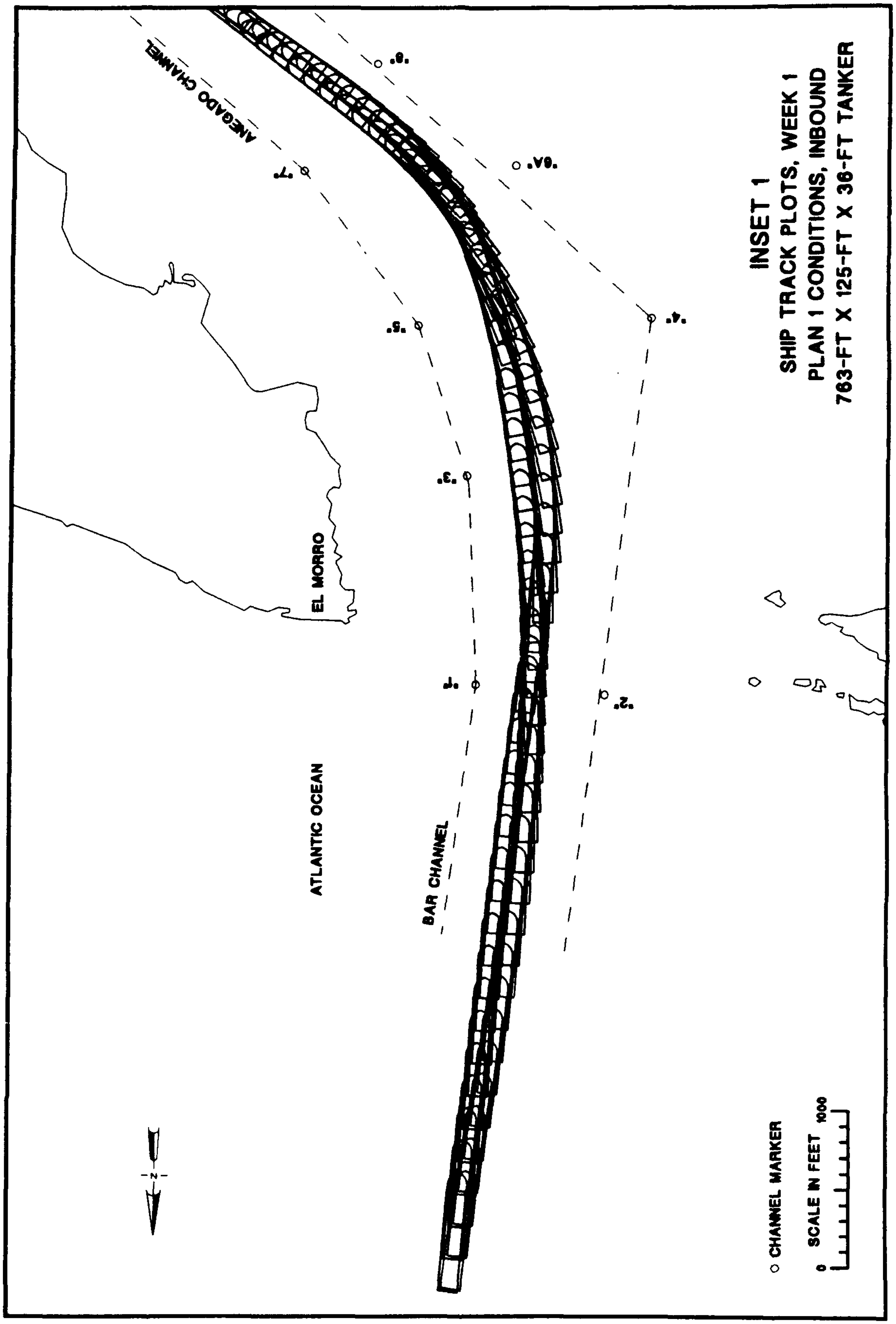
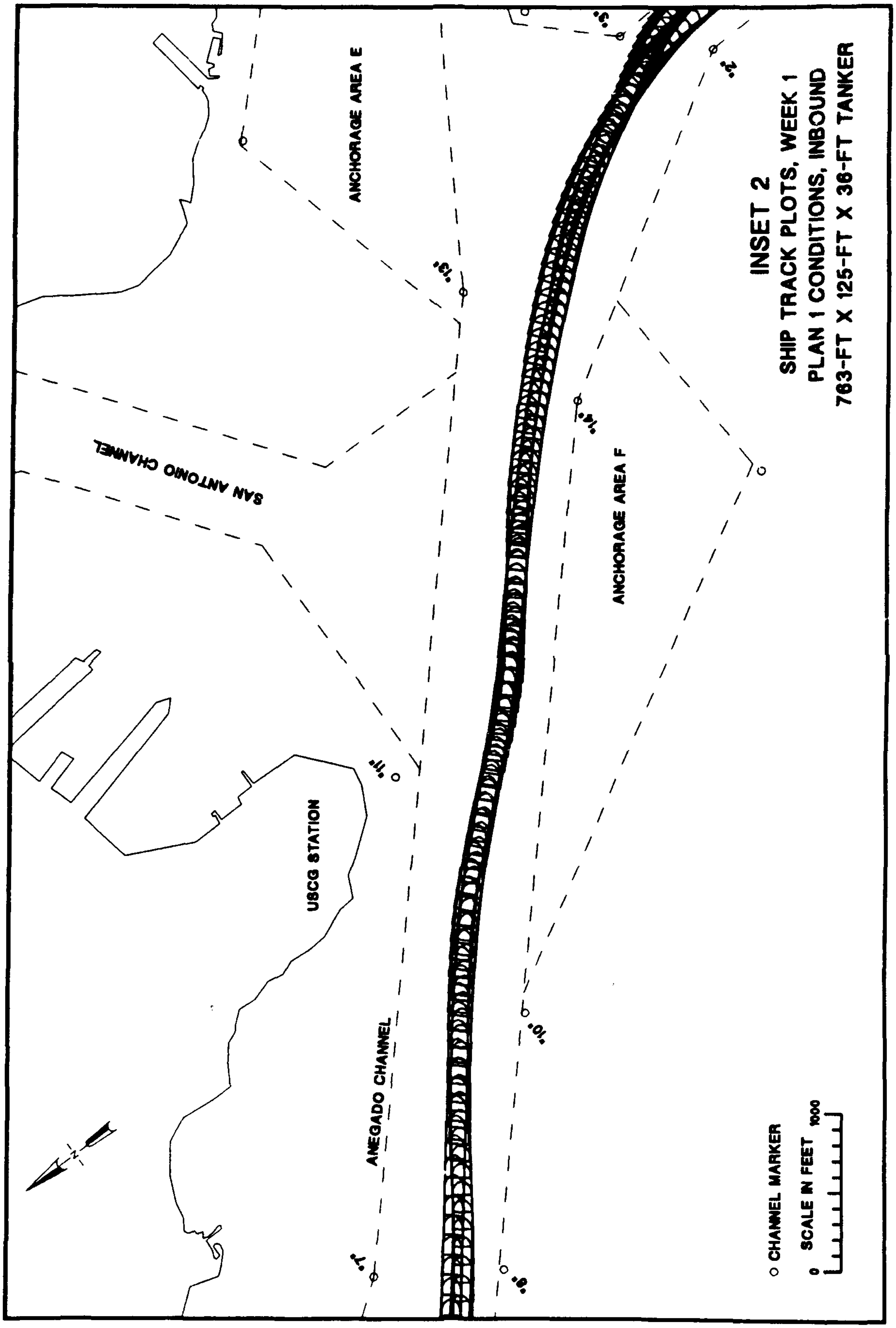
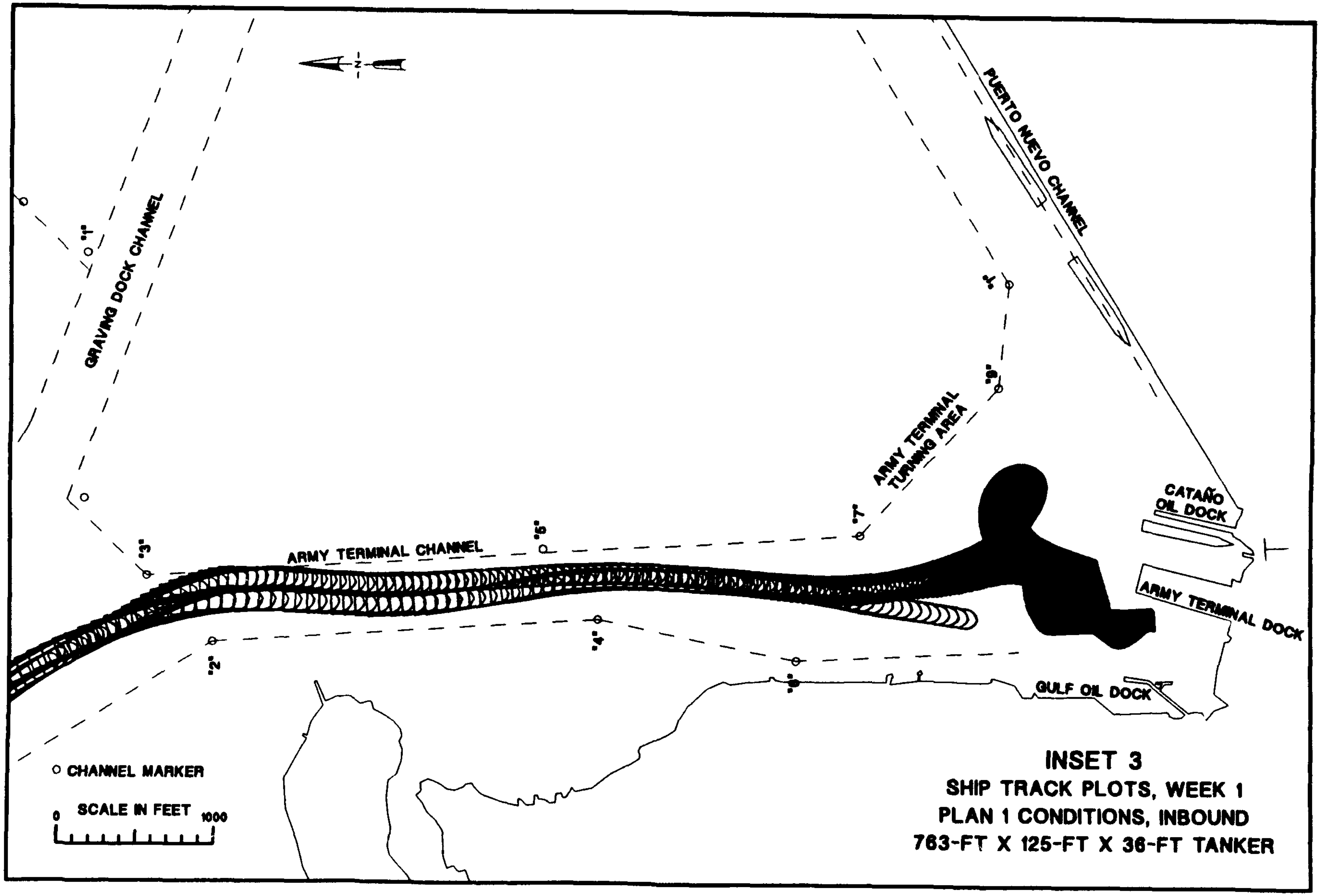
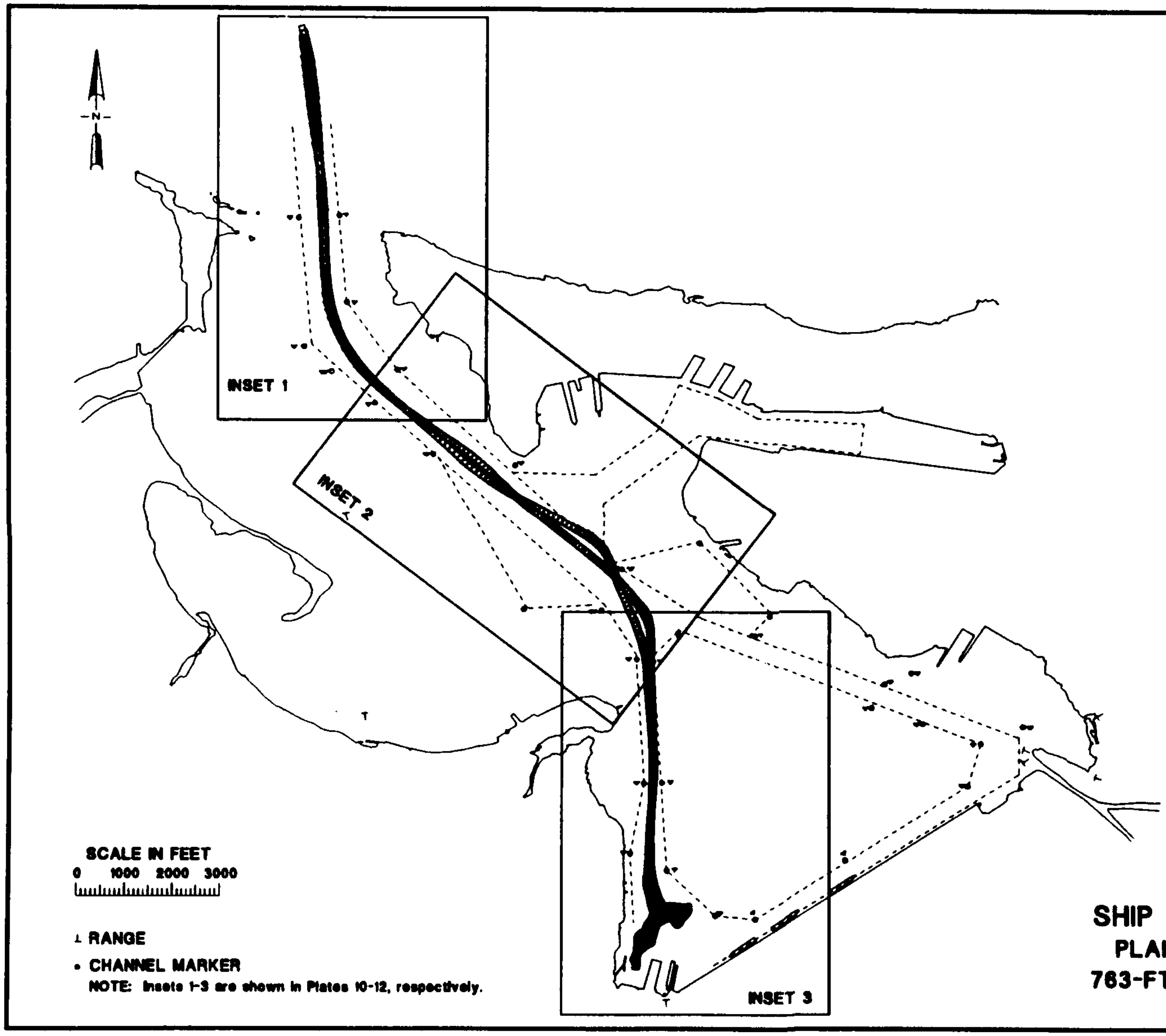

INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
1
2
3
4
5
6
6A
7
N
CHANNEL MARKER
SCALE IN FEET
0
1000

Plate 6


INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
N
"5"
"2"
"13"
"14"
"11"
"10"
"7"
"8"
CHANNEL MARKER
SCALE IN FEET
0
1000



INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER



SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER

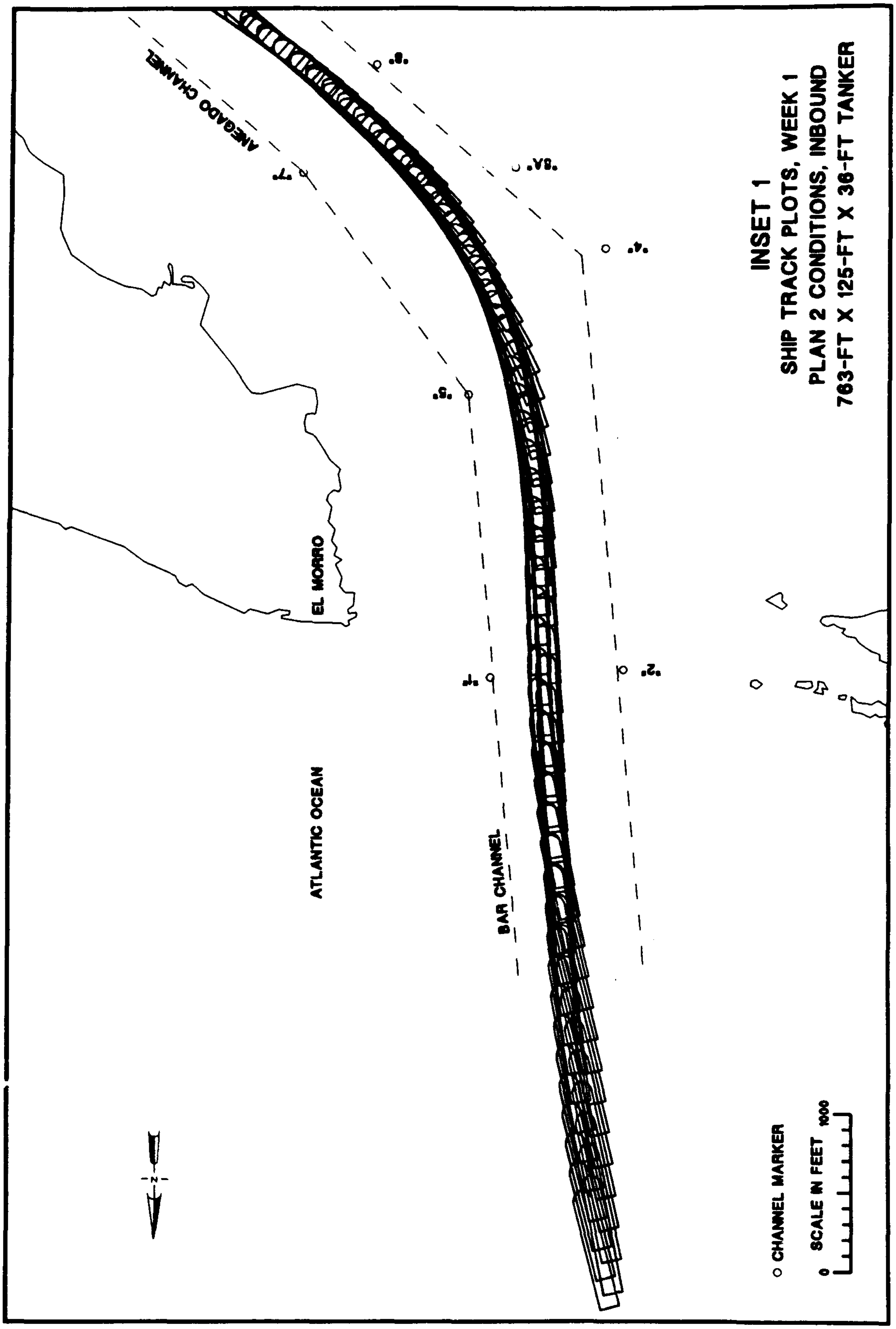
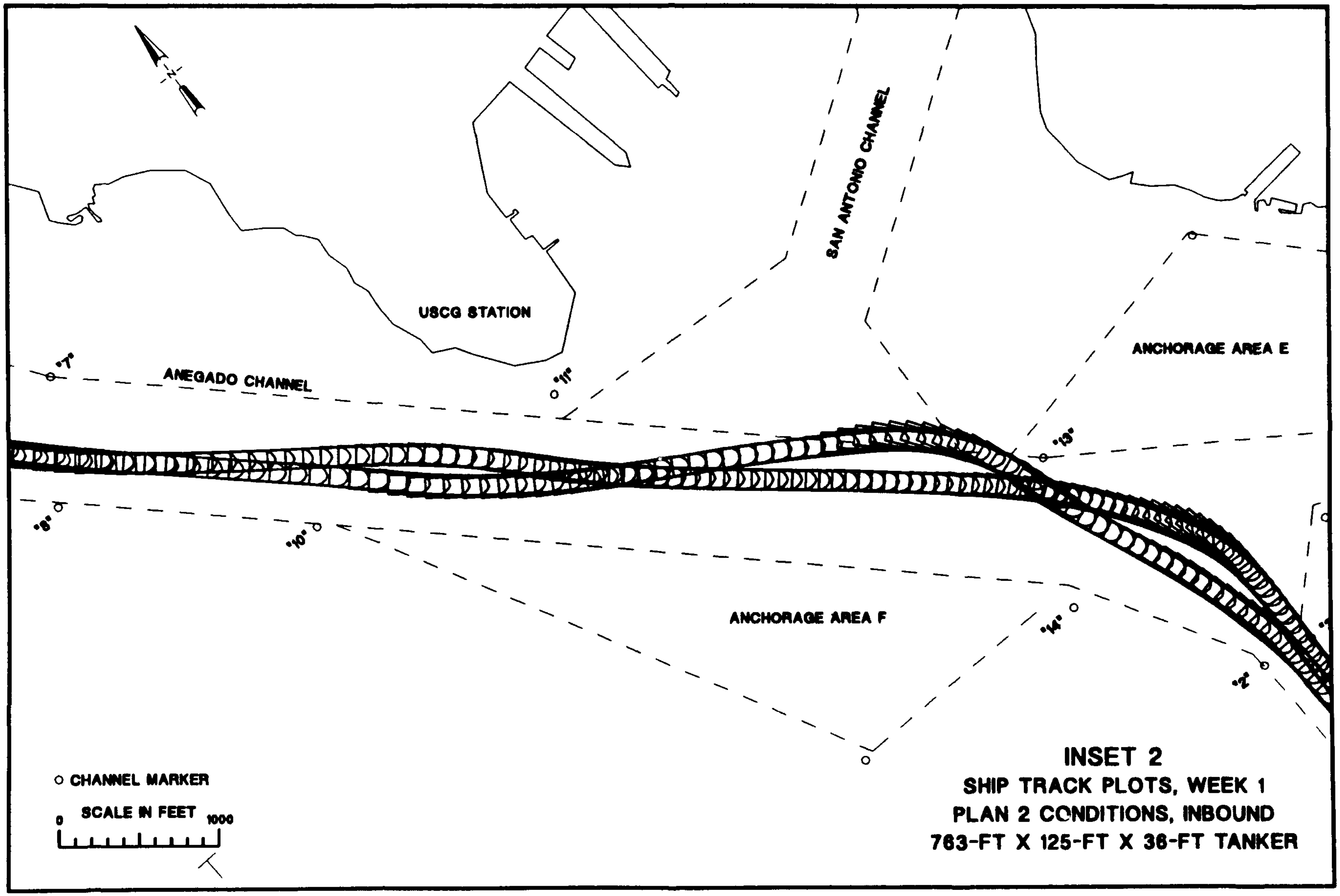
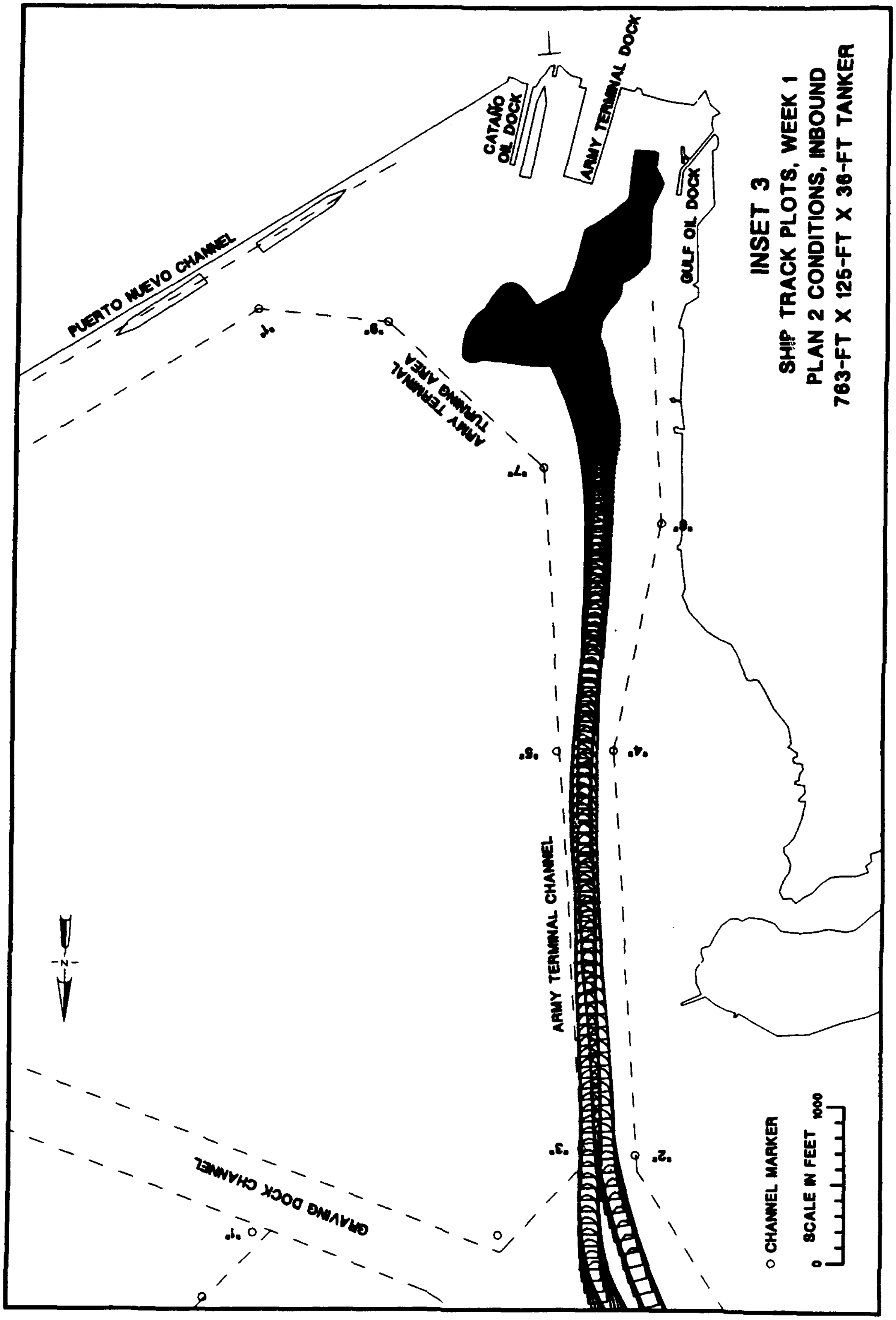
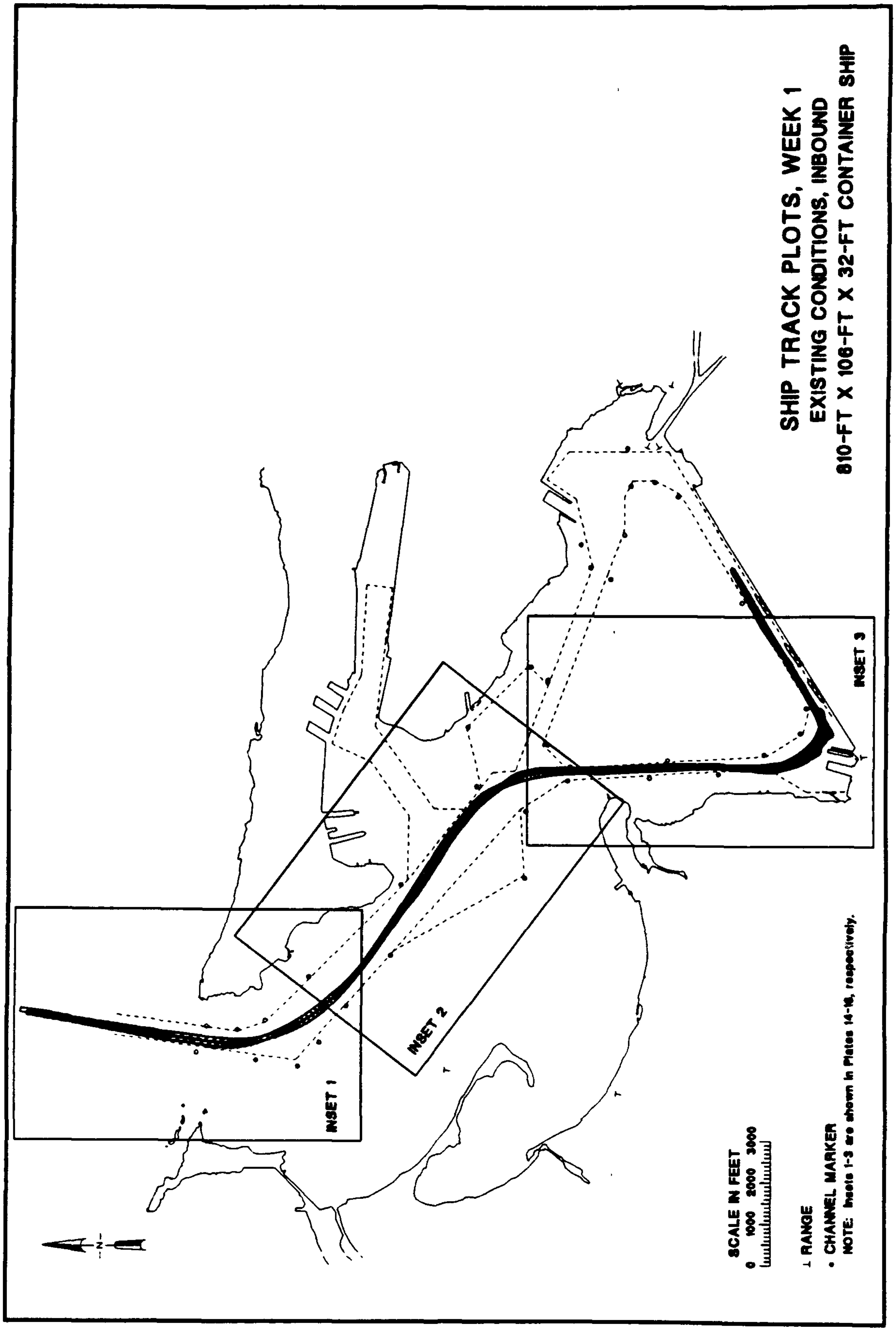

INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
"1"
"2"
"3"
"4"
"7"
"8"
"8A"
N
○ CHANNEL MARKER
SCALE IN FEET
0
1000

Plate 10

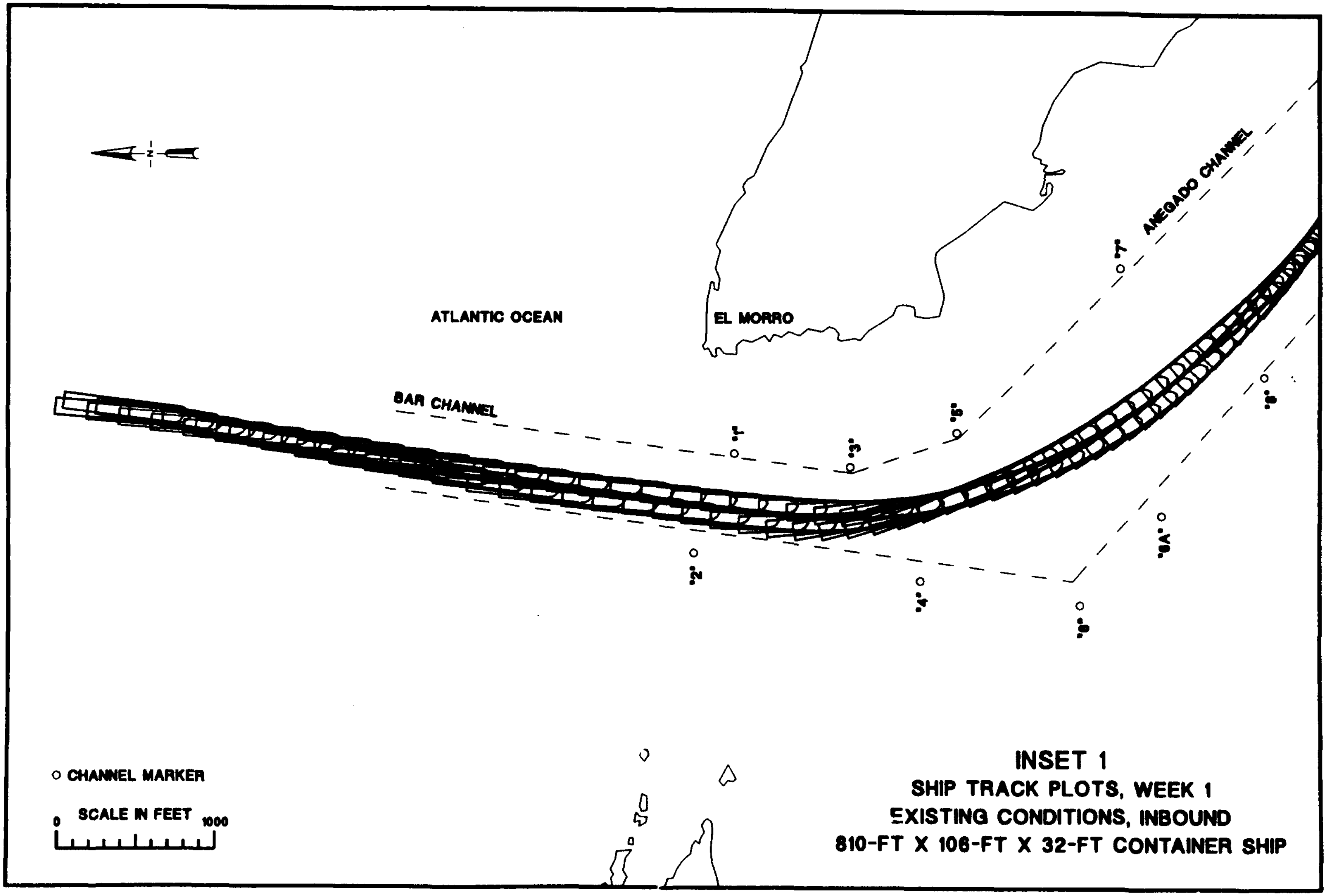


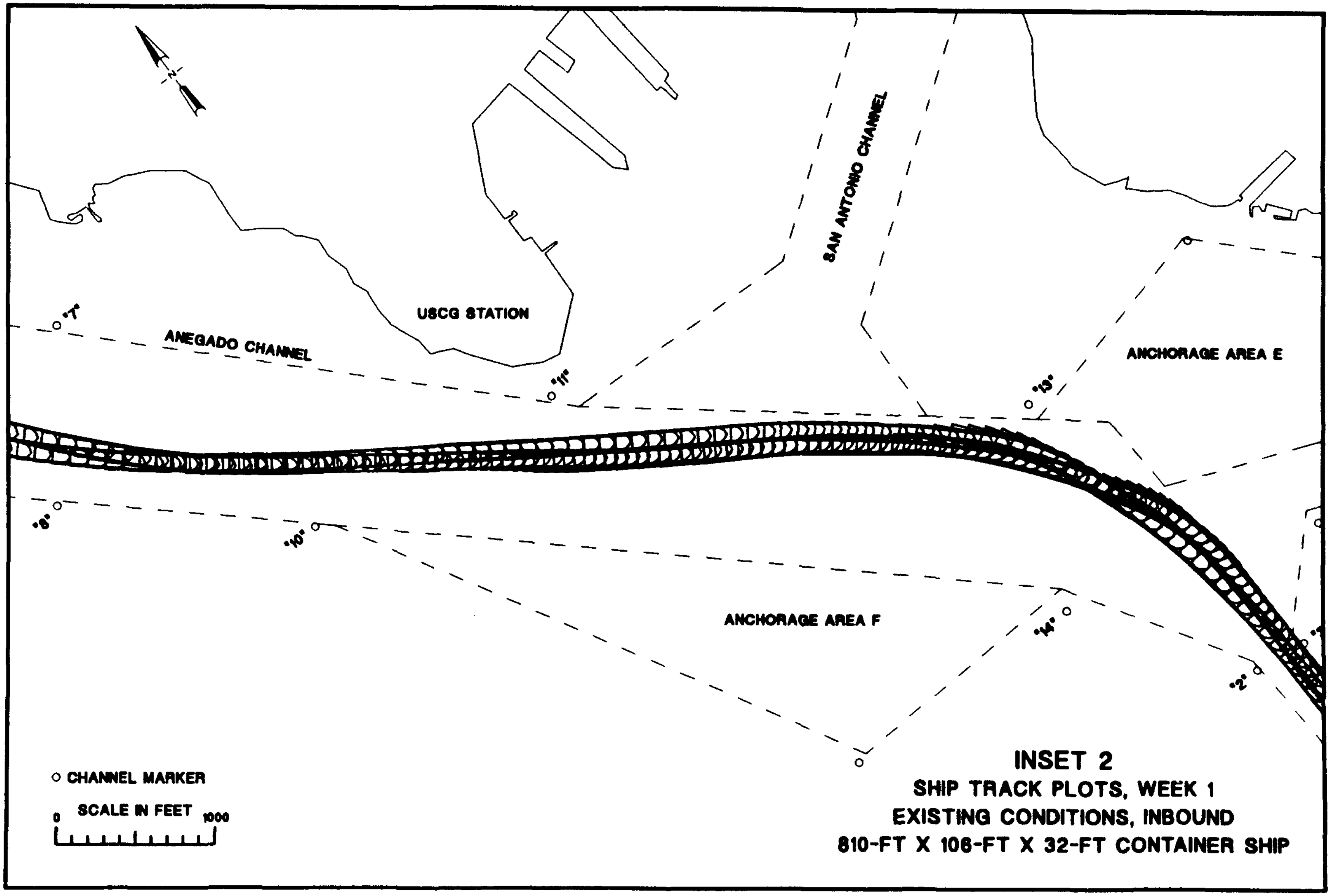
INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
763-FT X 125-FT X 38-FT TANKER


INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N

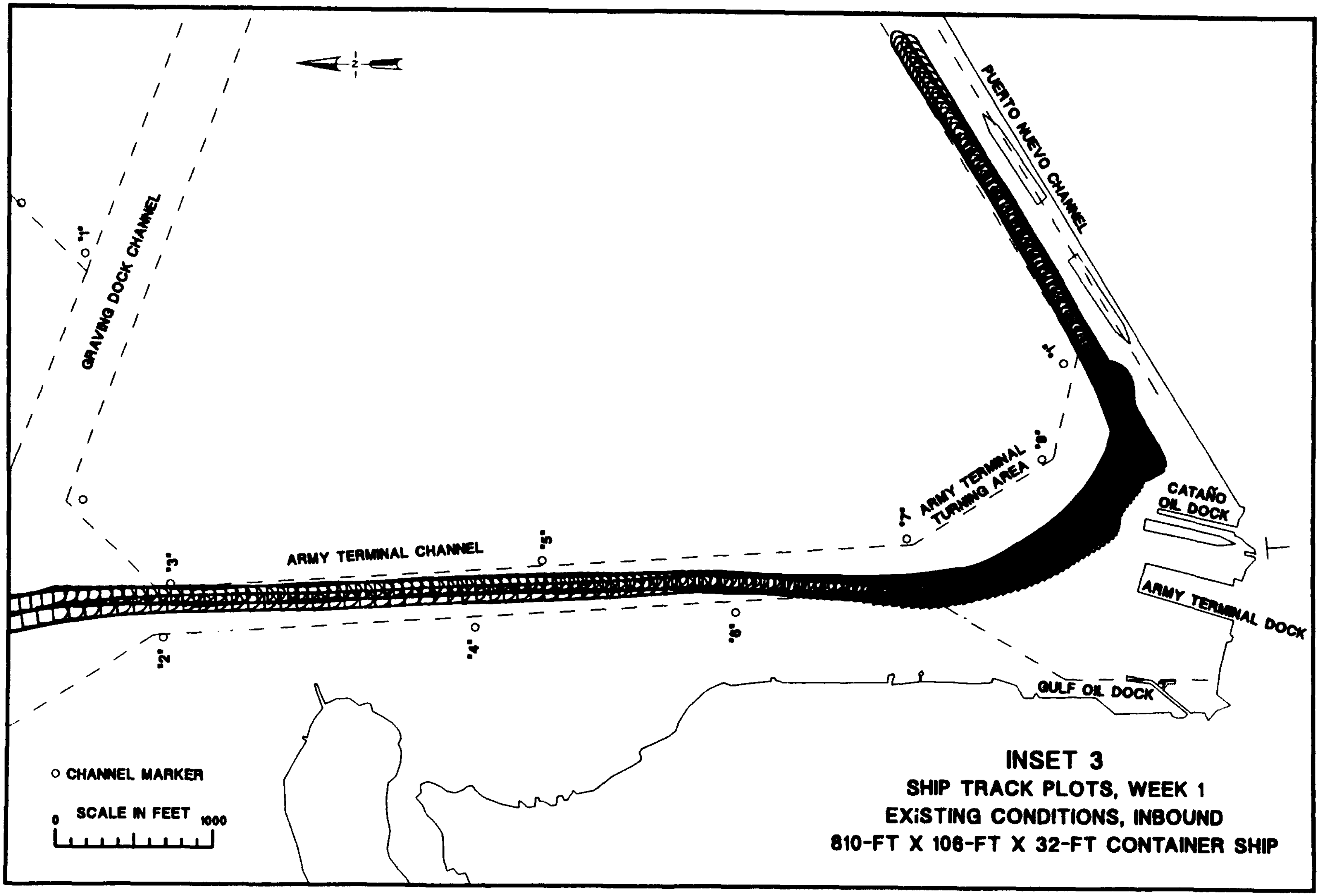


SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

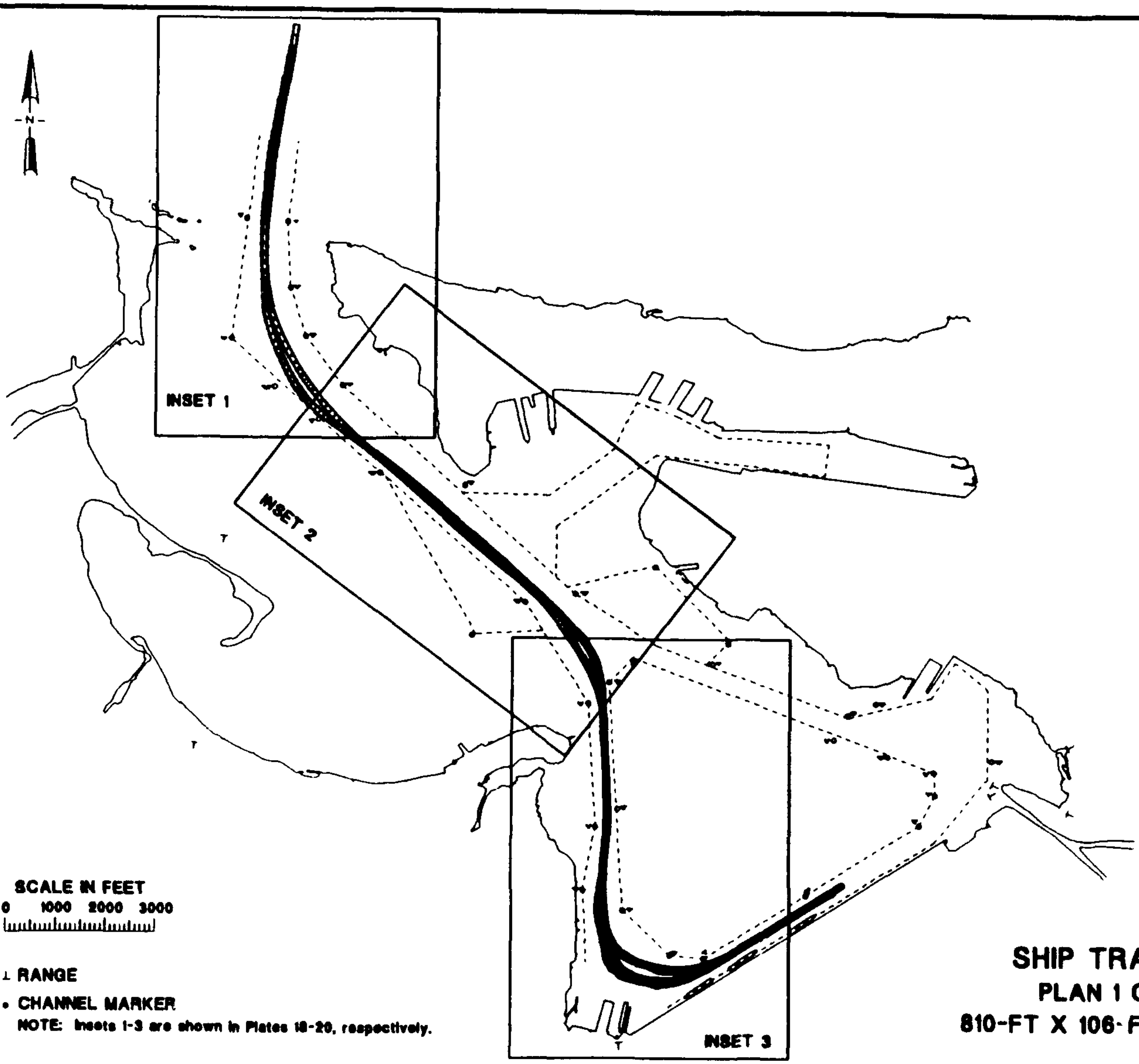

N
ATLANTIC OCEAN
EL MORRO
ANEGADO CHANNEL
BAR CHANNEL
1
2
3
4
5
6
6A
7
8
9
○ CHANNEL MARKER
SCALE IN FEET
0
1000
INSET 1
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP



INSET 2
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP



INSET 3
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP



SCALE IN FEET
0 1000 2000 3000

⊥ RANGE

• CHANNEL MARKER

NOTE: Insets 1-3 are shown in Plates 18-20, respectively.

SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

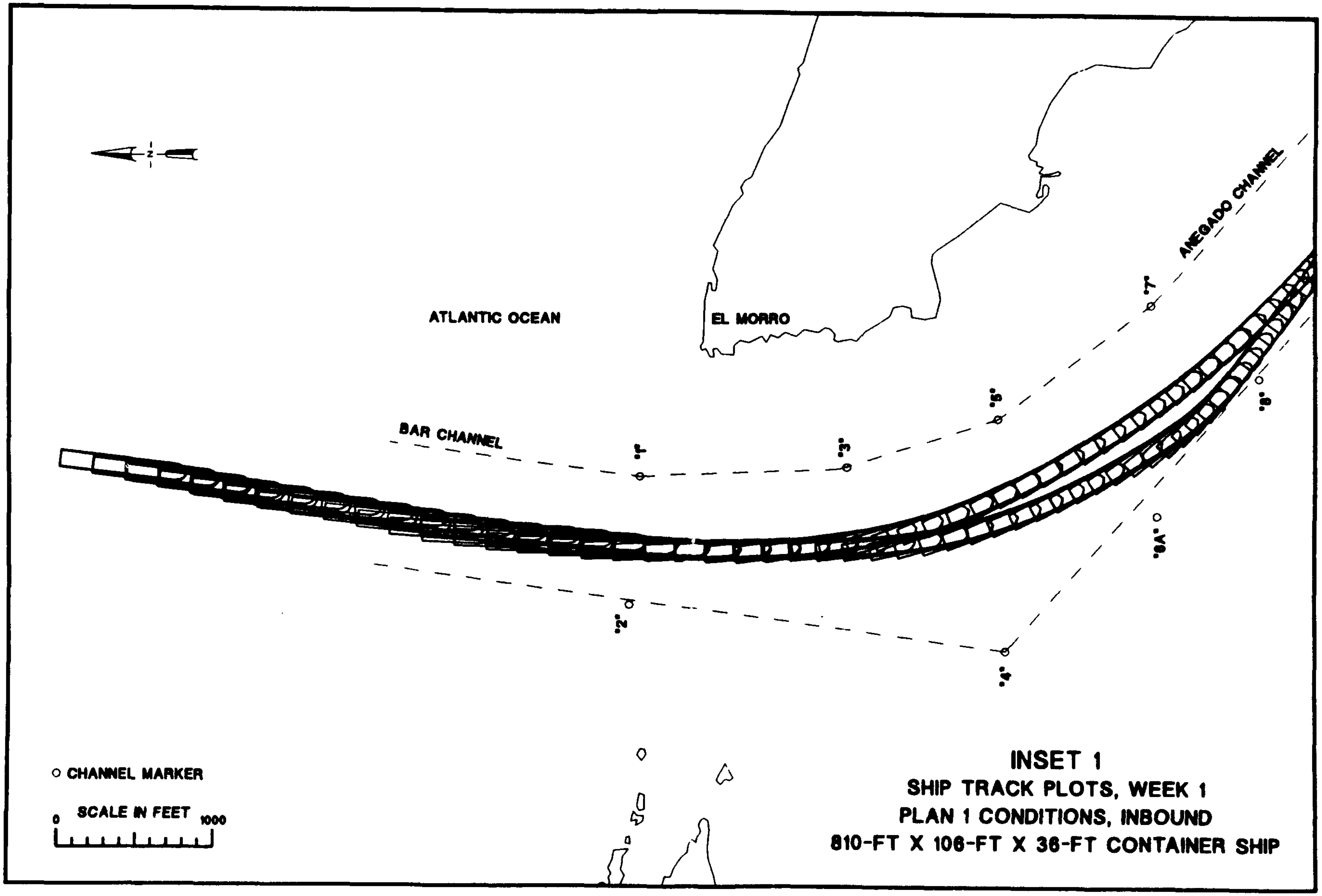
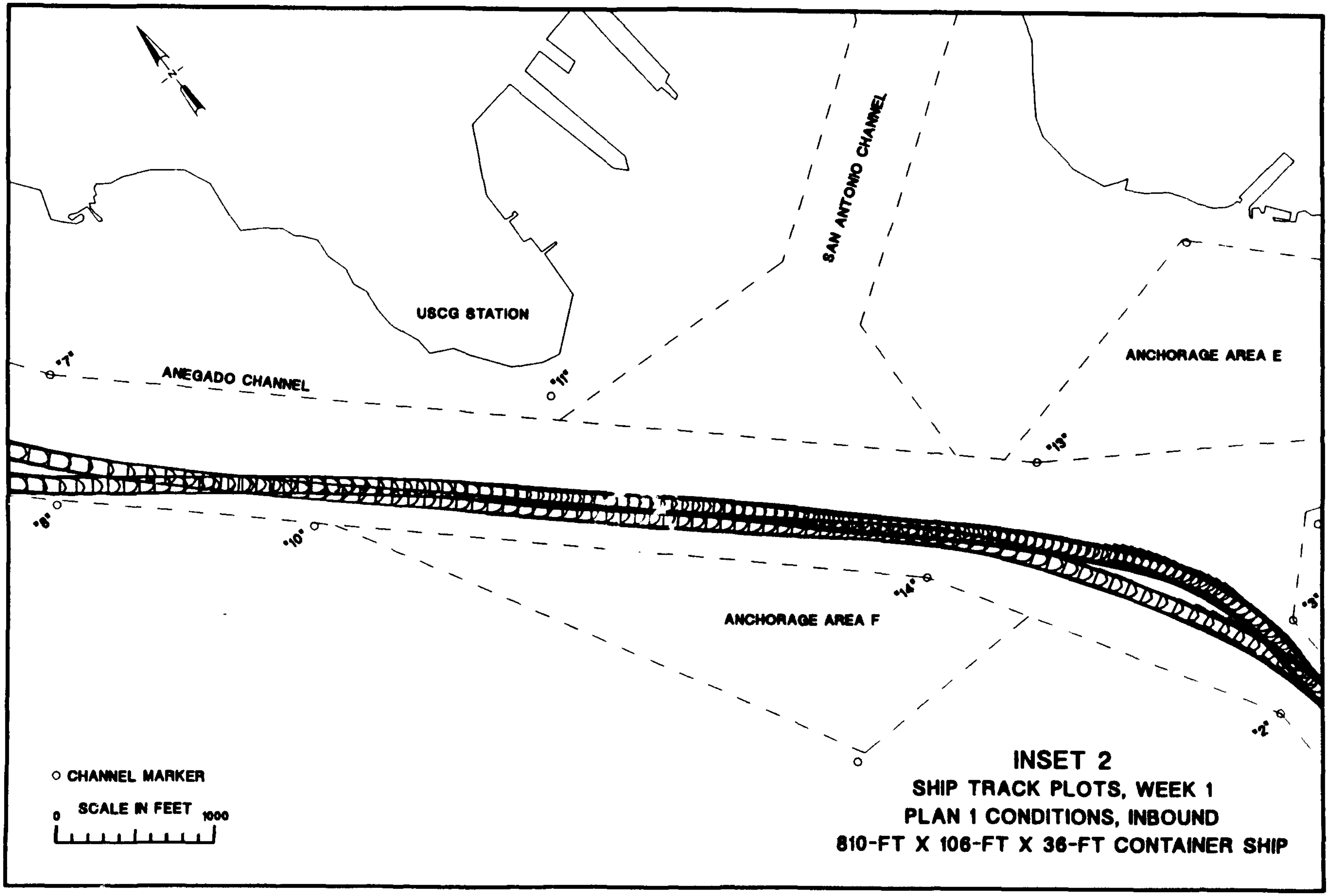
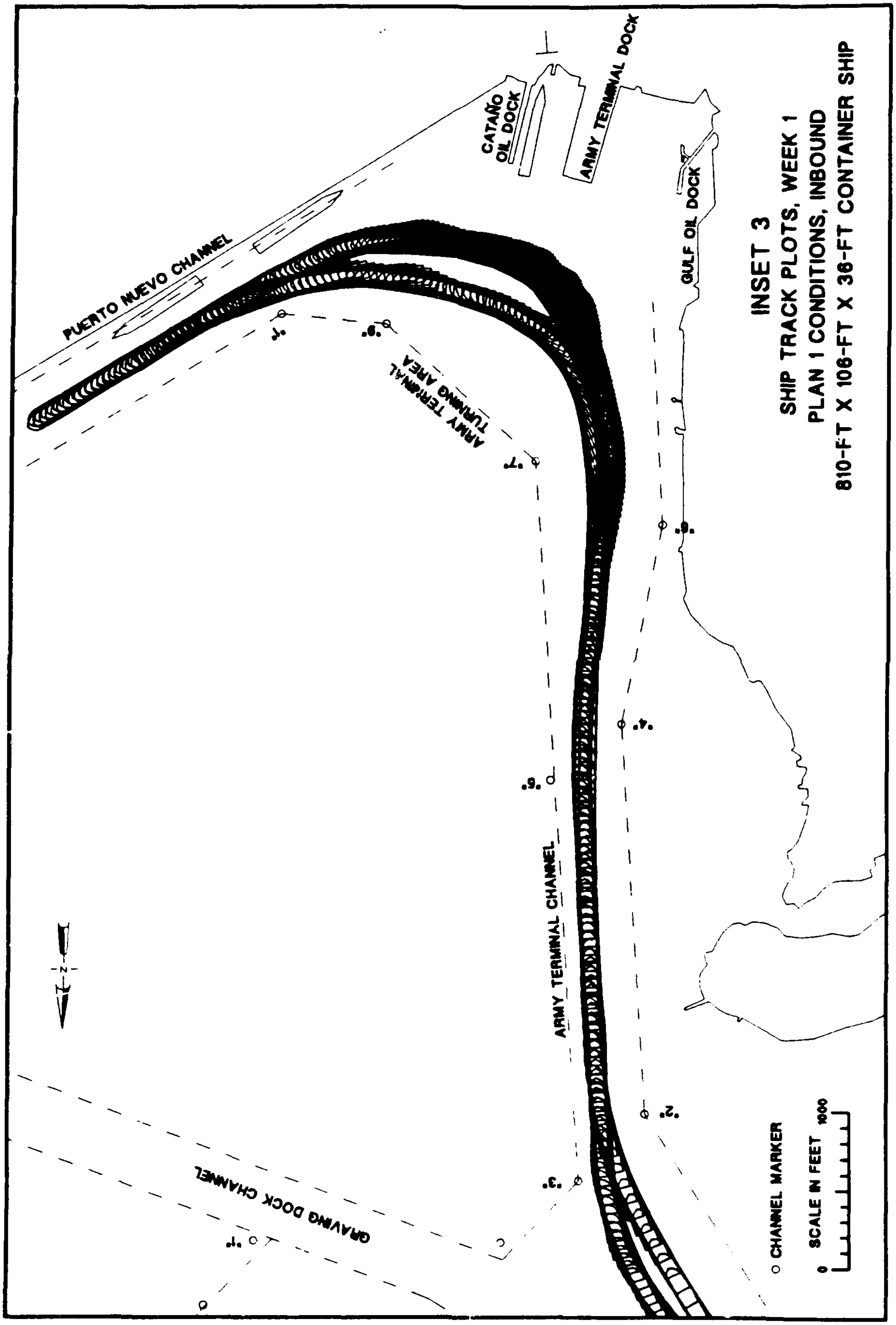

ATLANTIC OCEAN
EL MORRO
ANEGADO CHANNEL
BAR CHANNEL
○ CHANNEL MARKER
SCALE IN FEET
0
1000
INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

Plate 18

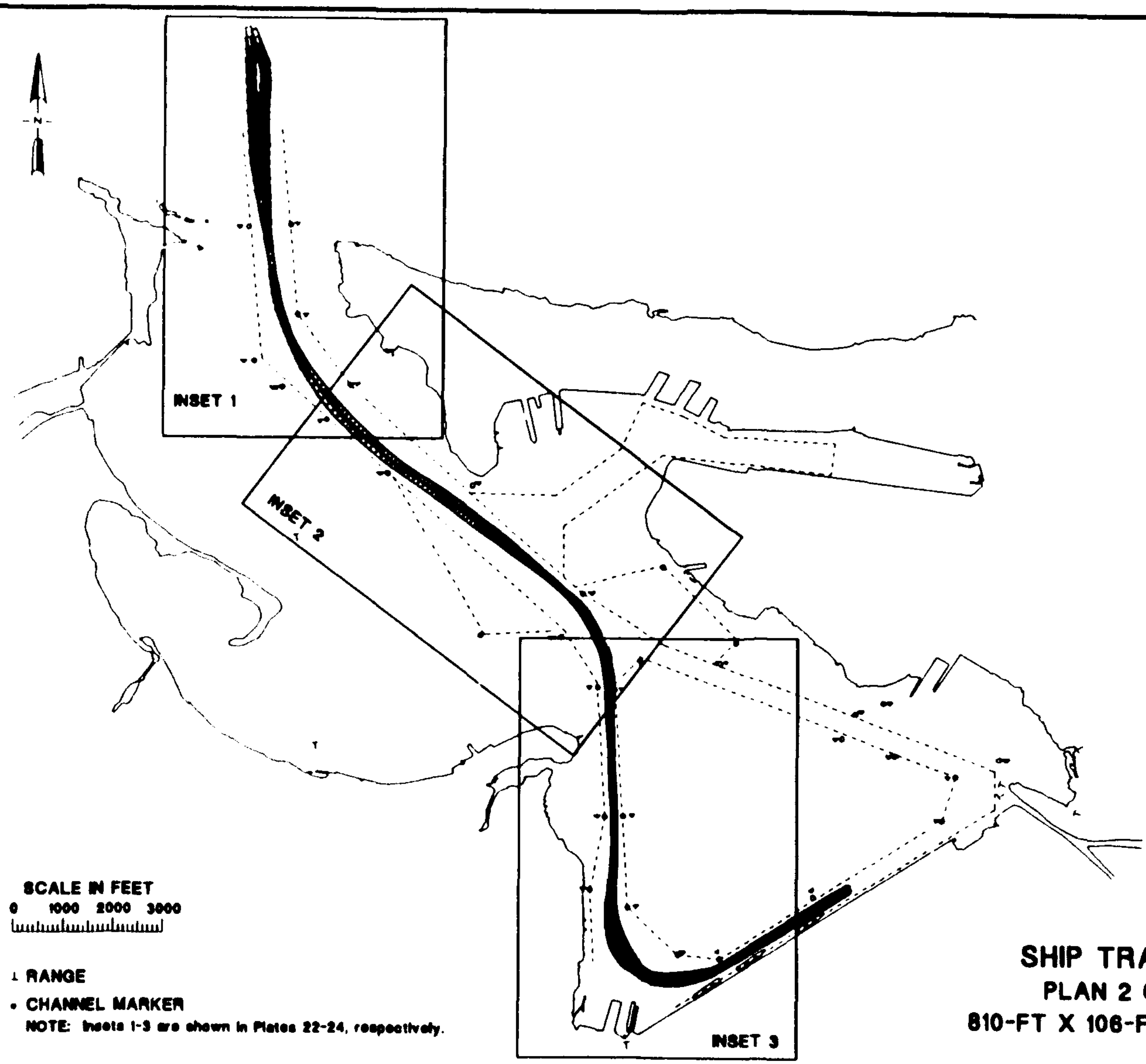


INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

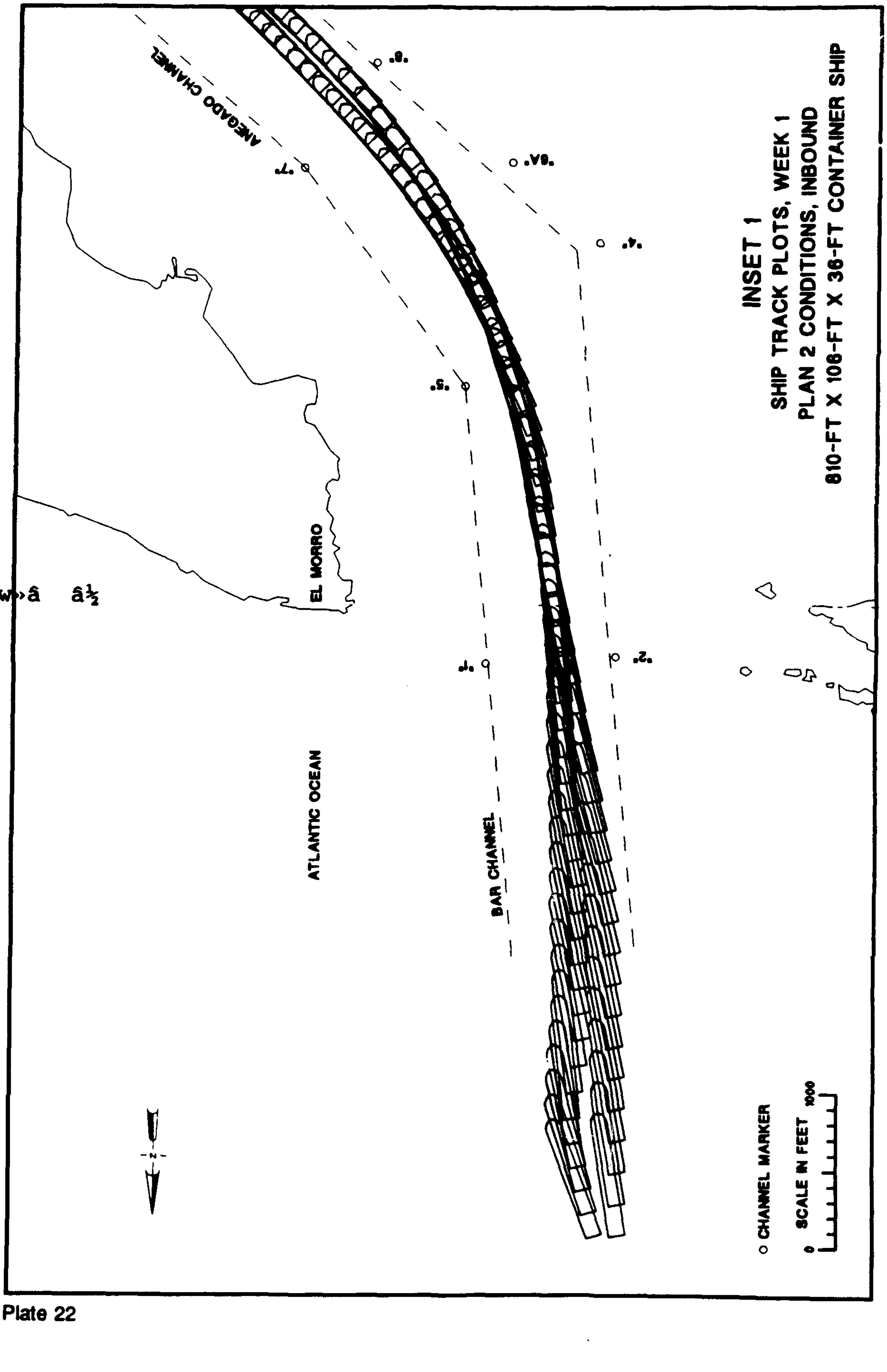


INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N

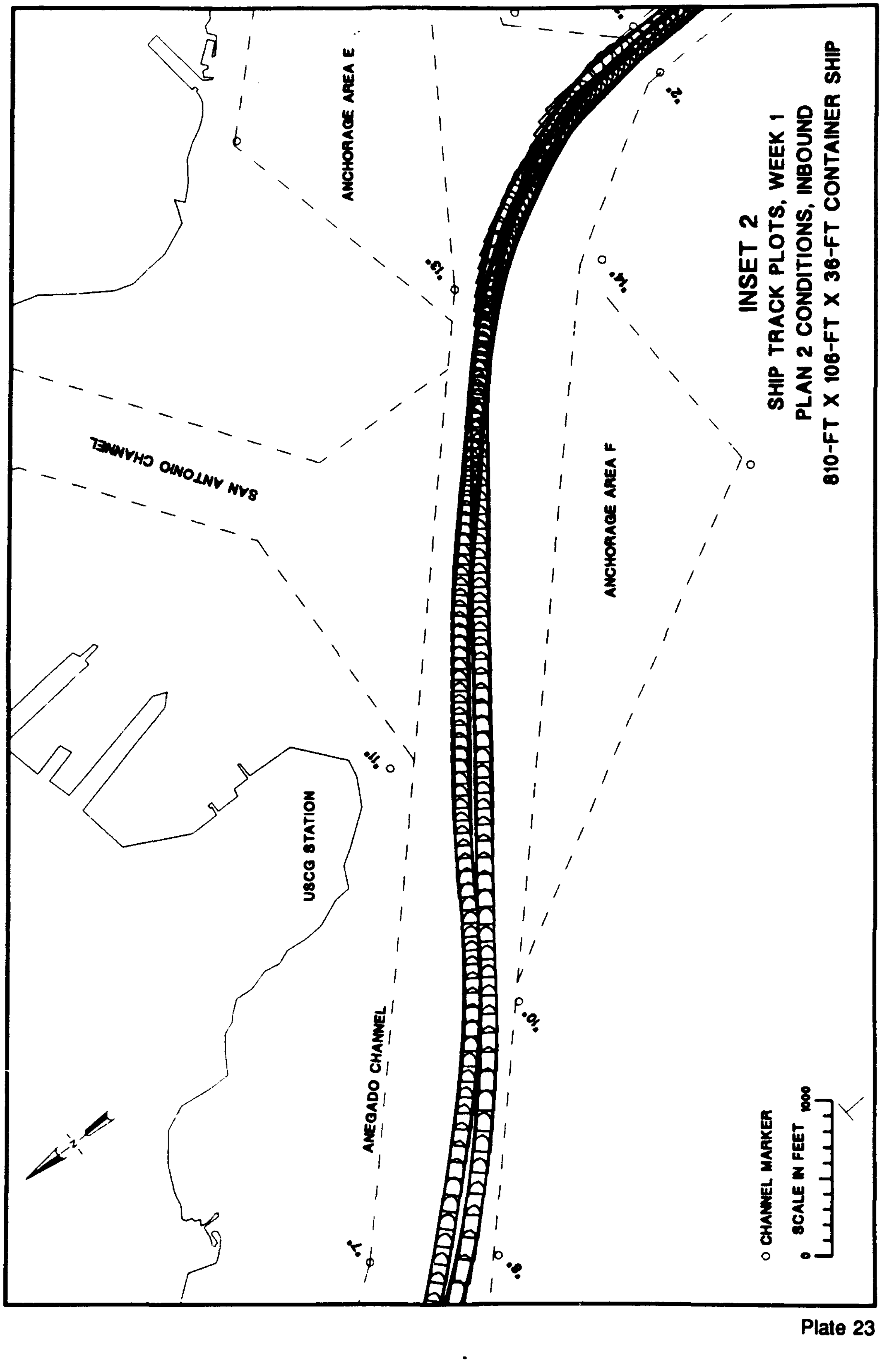
Plate 20

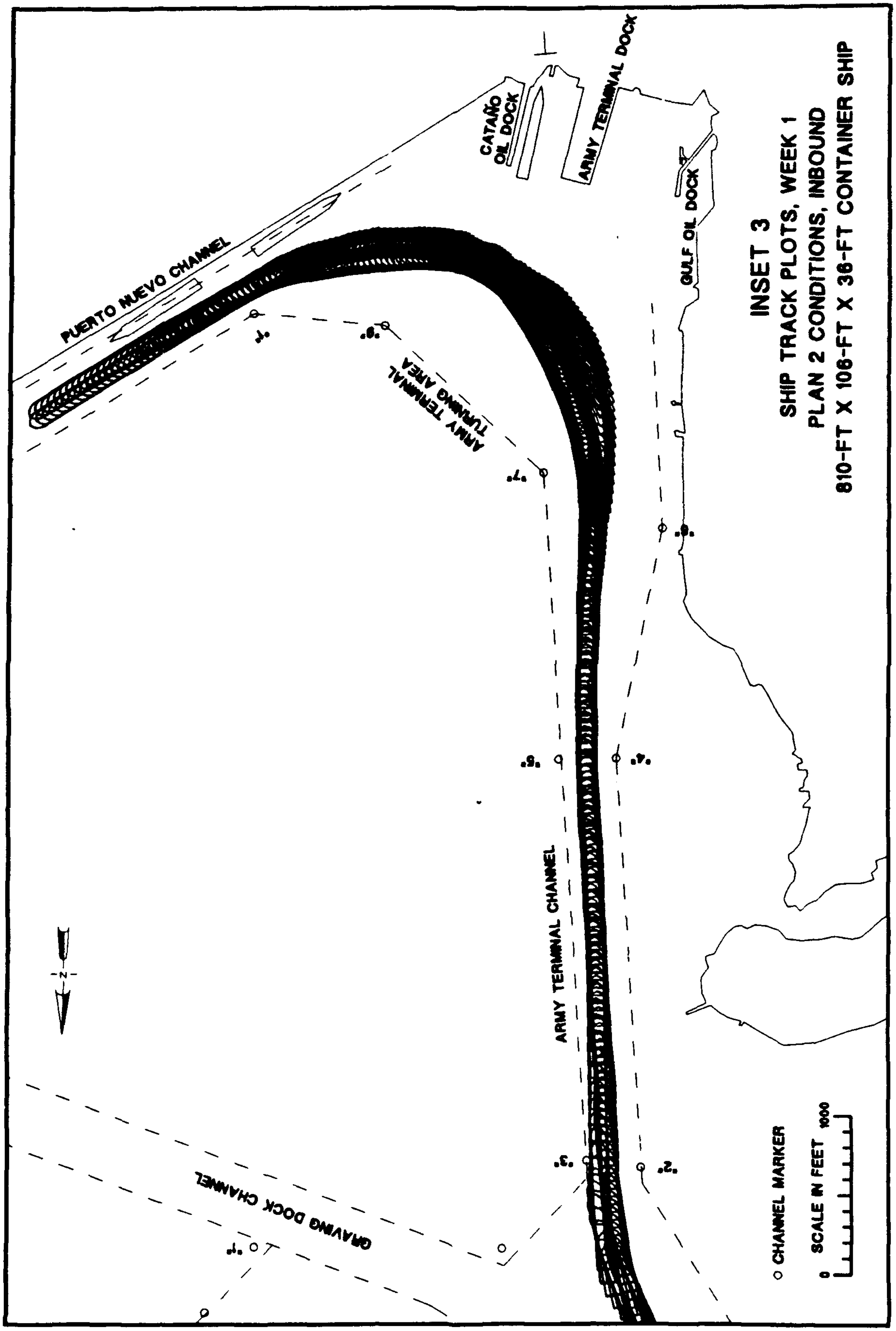


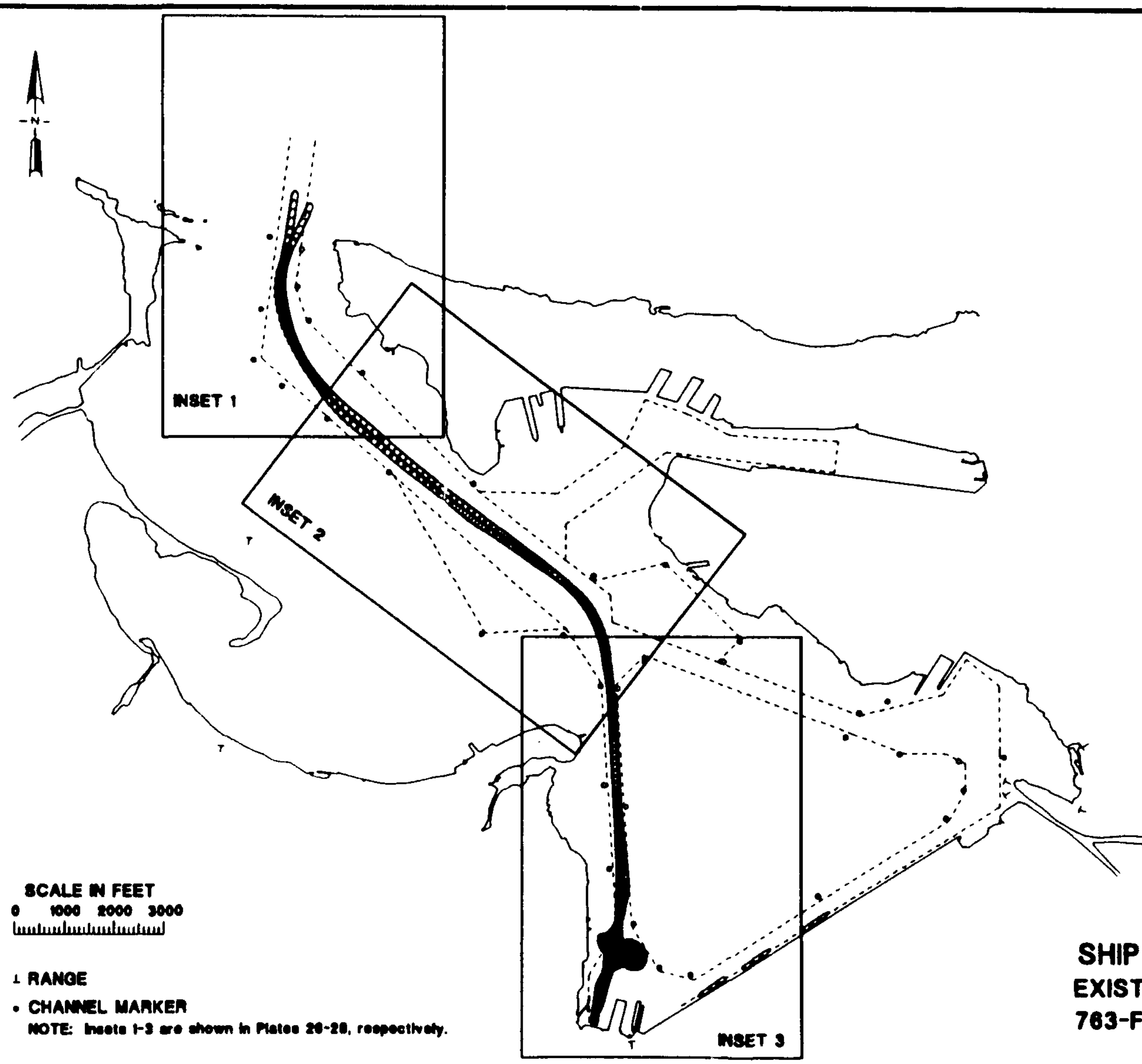
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



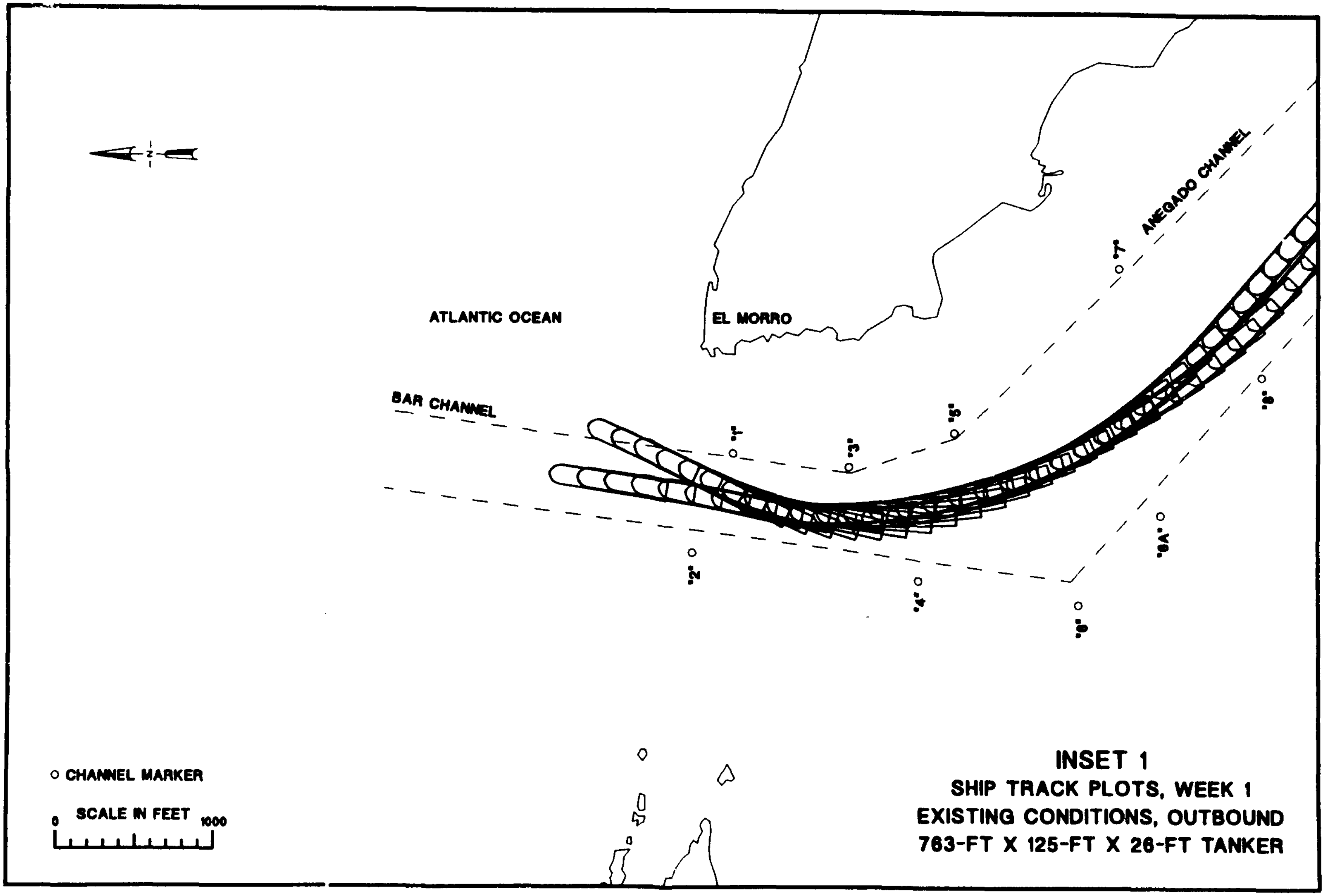
INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000

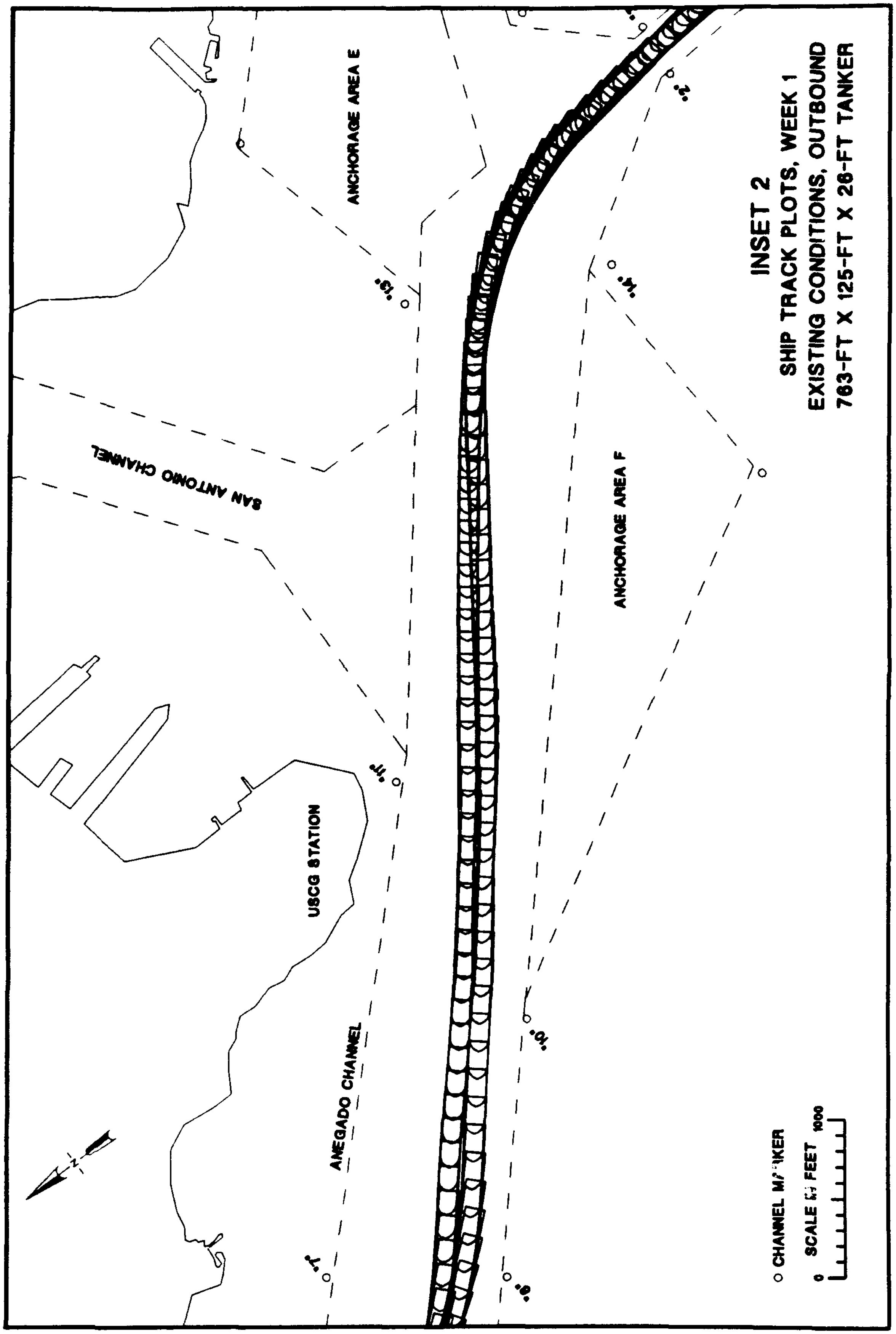

INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N

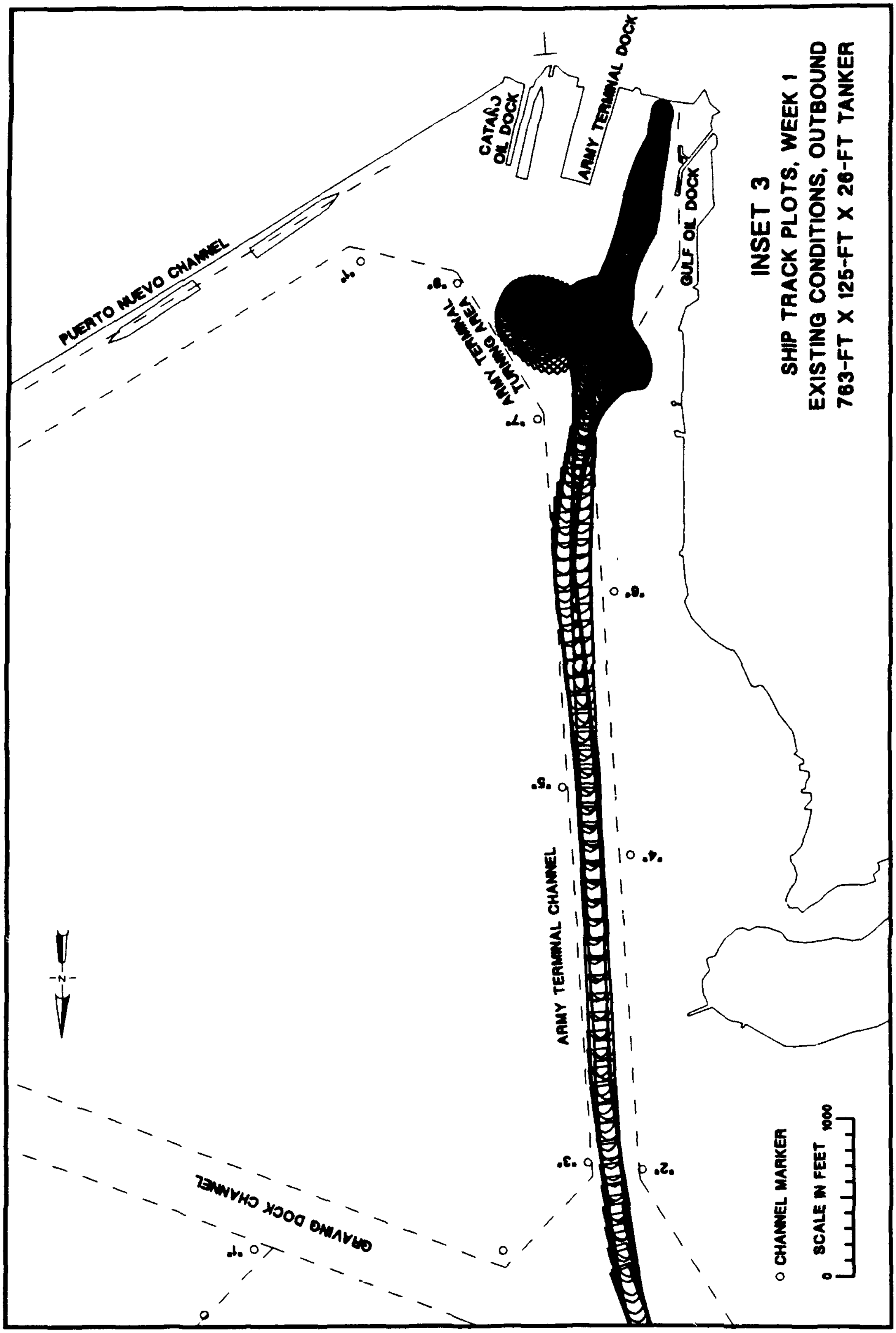

INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

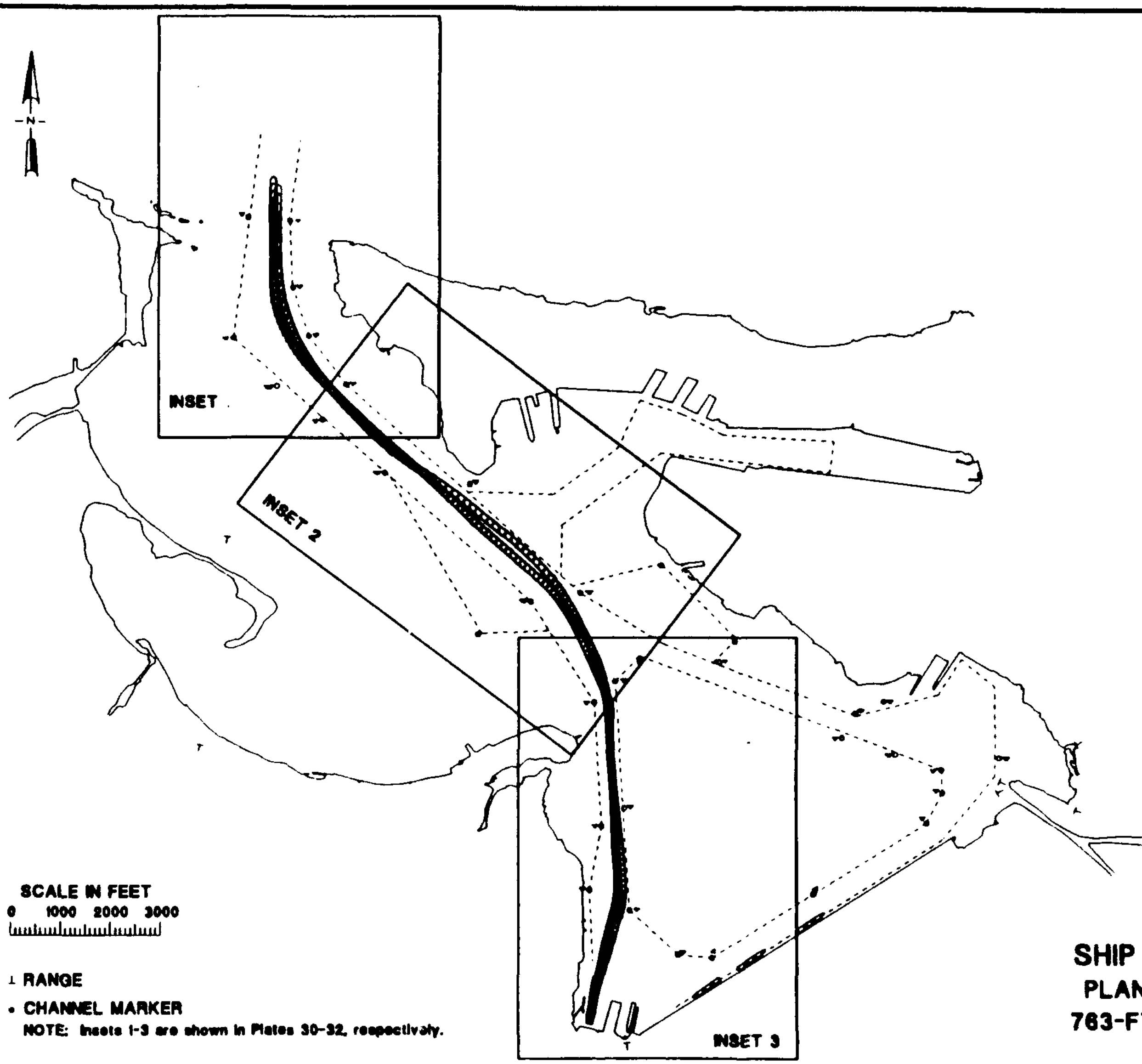


SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

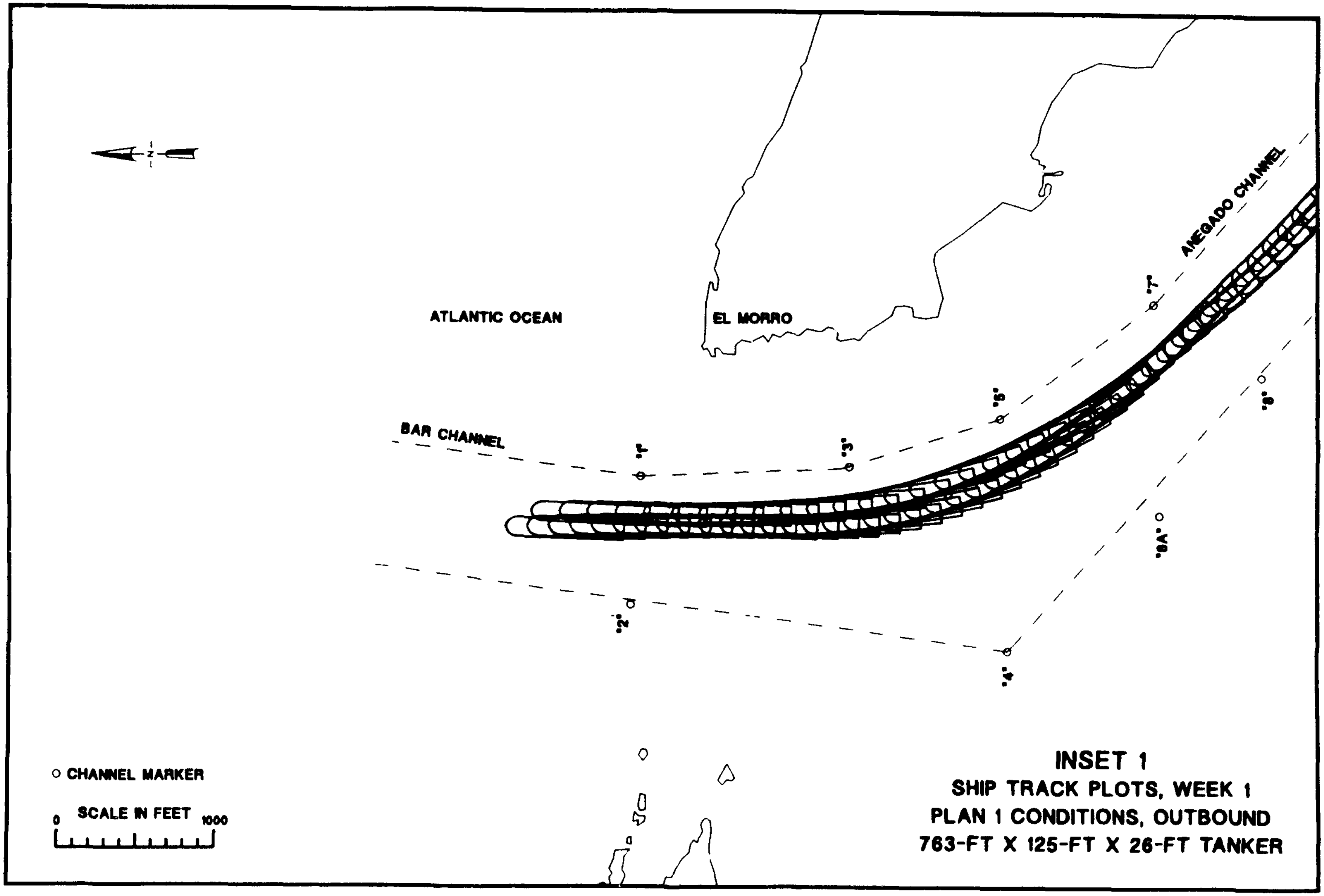

ATLANTIC OCEAN
EL MORRO
ANEGADO CHANNEL
BAR CHANNEL
"1"
"2"
"3"
"4"
"5"
"6"
"7"
"8"
"9"
"9A"
○ CHANNEL MARKER
SCALE IN FEET
0
1000
N
INSET 1
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER


INSET 2
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
SCALE IN FEET
0
1000

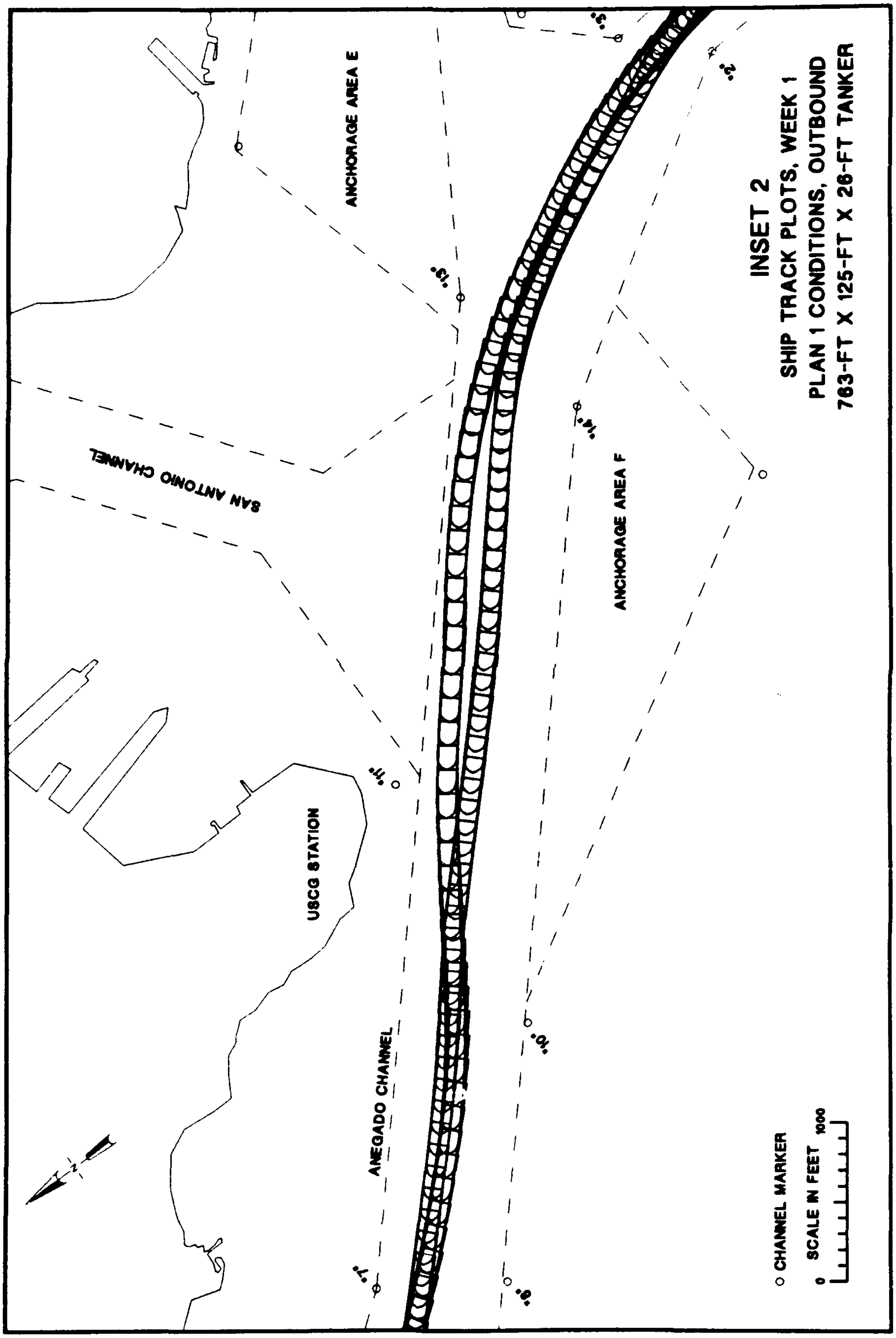

INSET 3
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

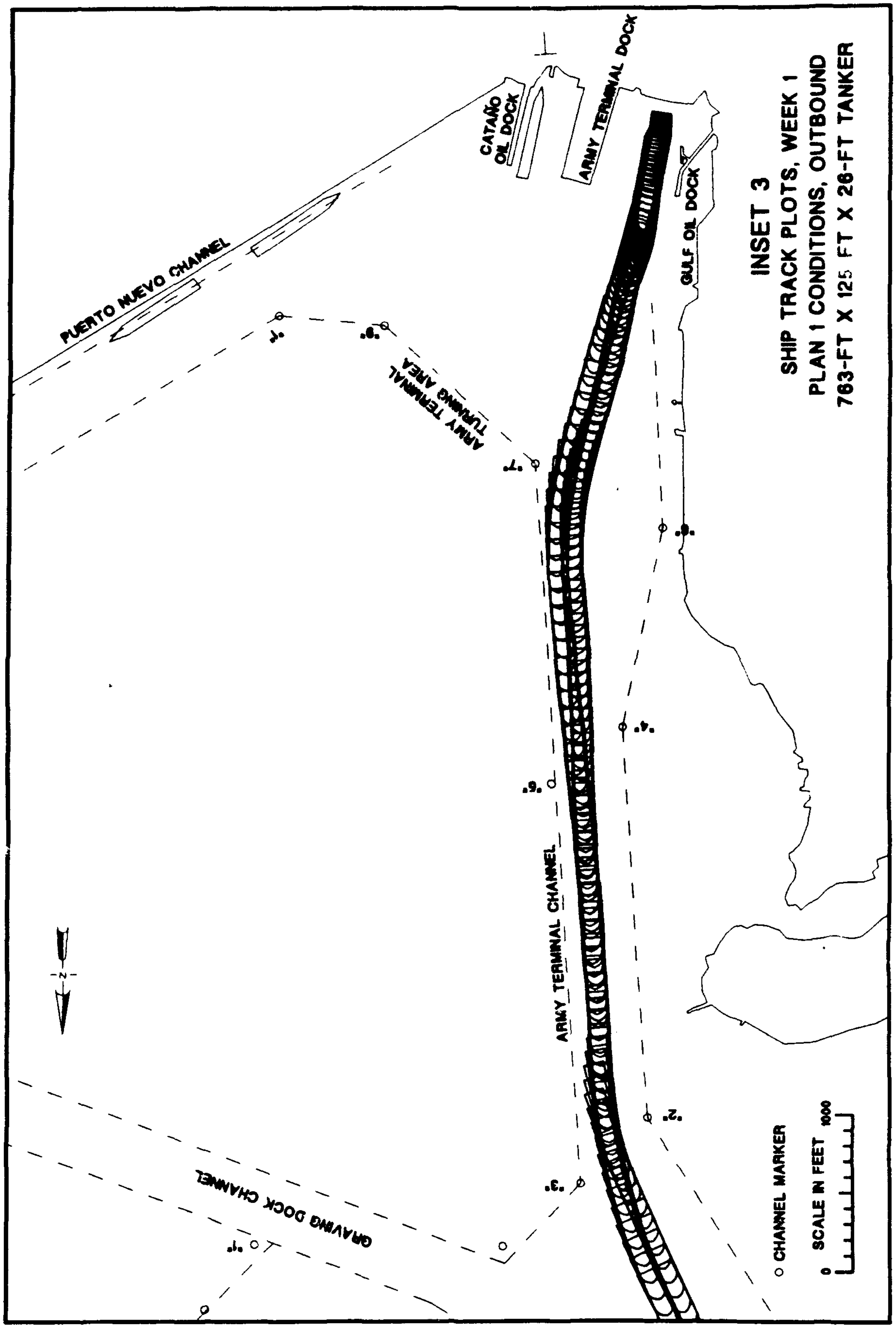


SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

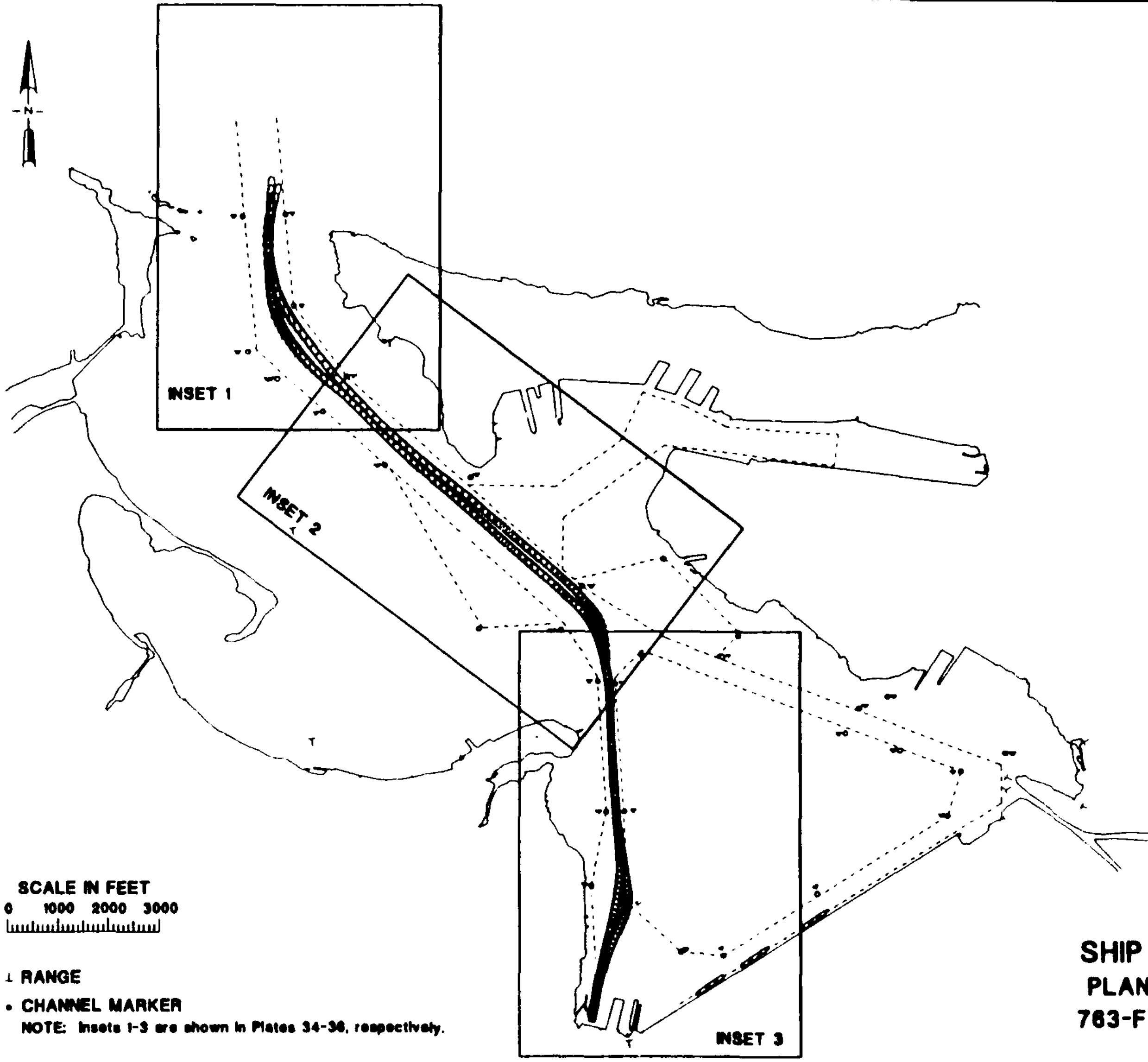


INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

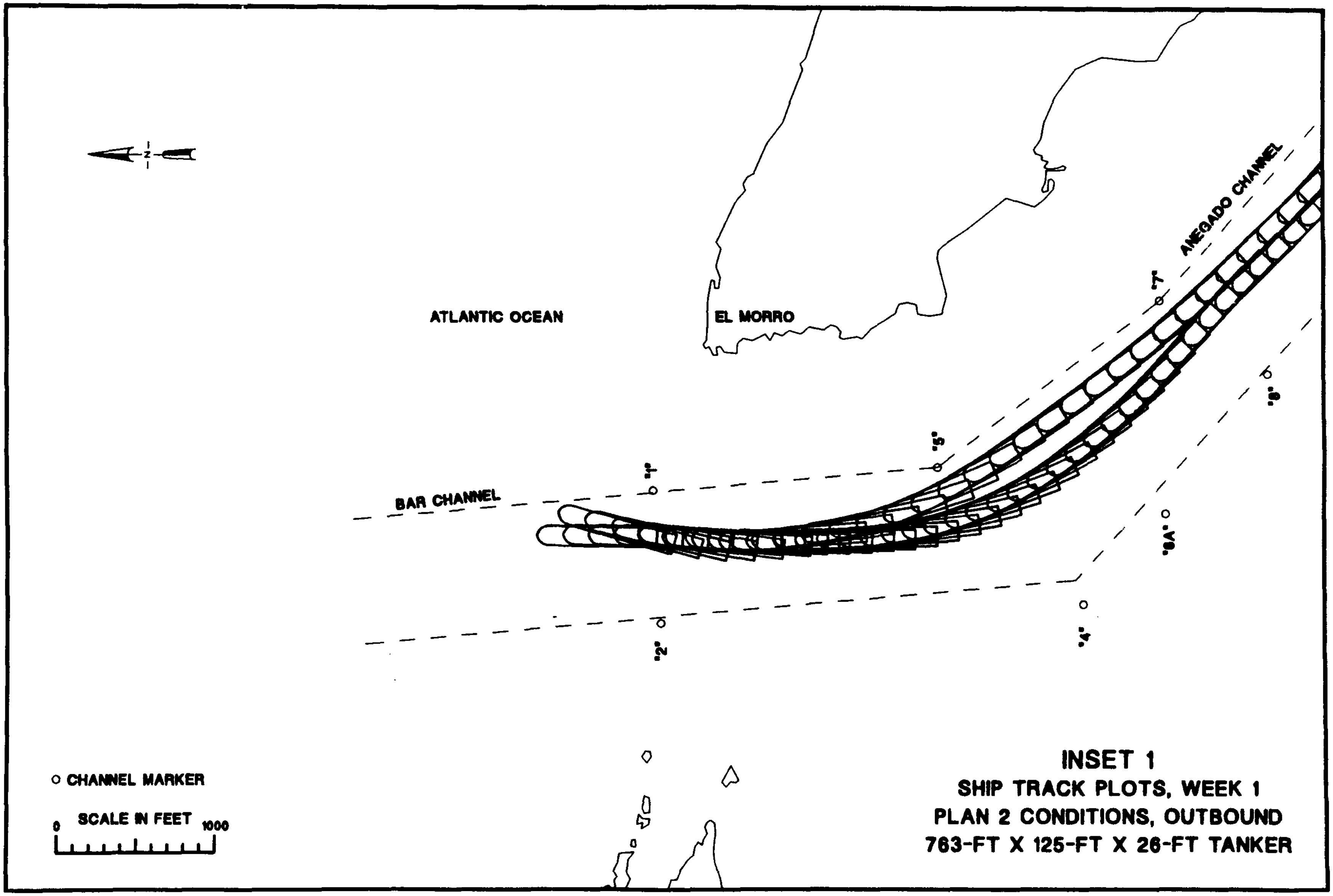

INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
ANCHORAGE AREA E
SAN ANTONIO CHANNEL
ANCHORAGE AREA F
USCG STATION
ANEGADO CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000



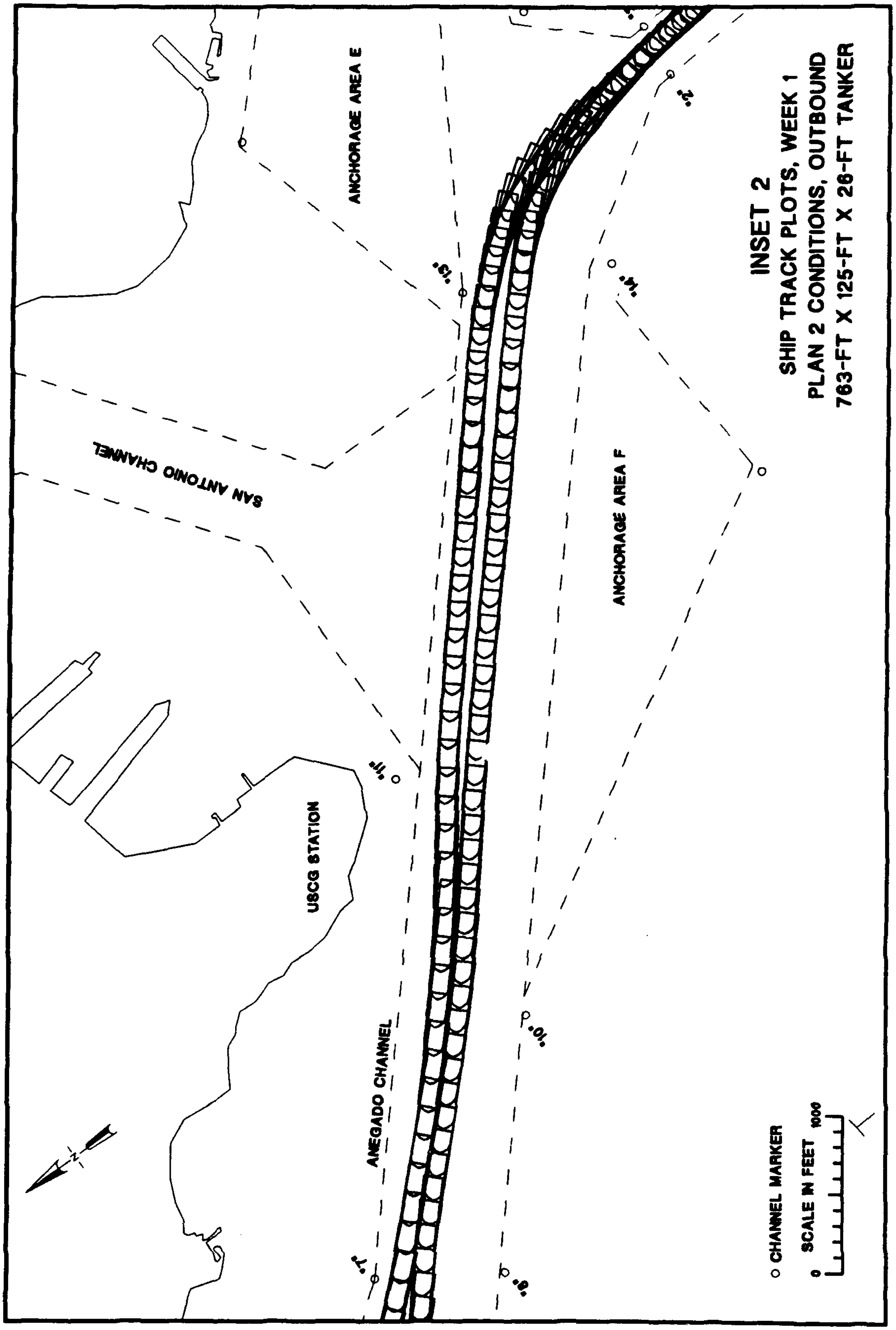
INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
763-FT X 125 FT X 26-FT TANKER

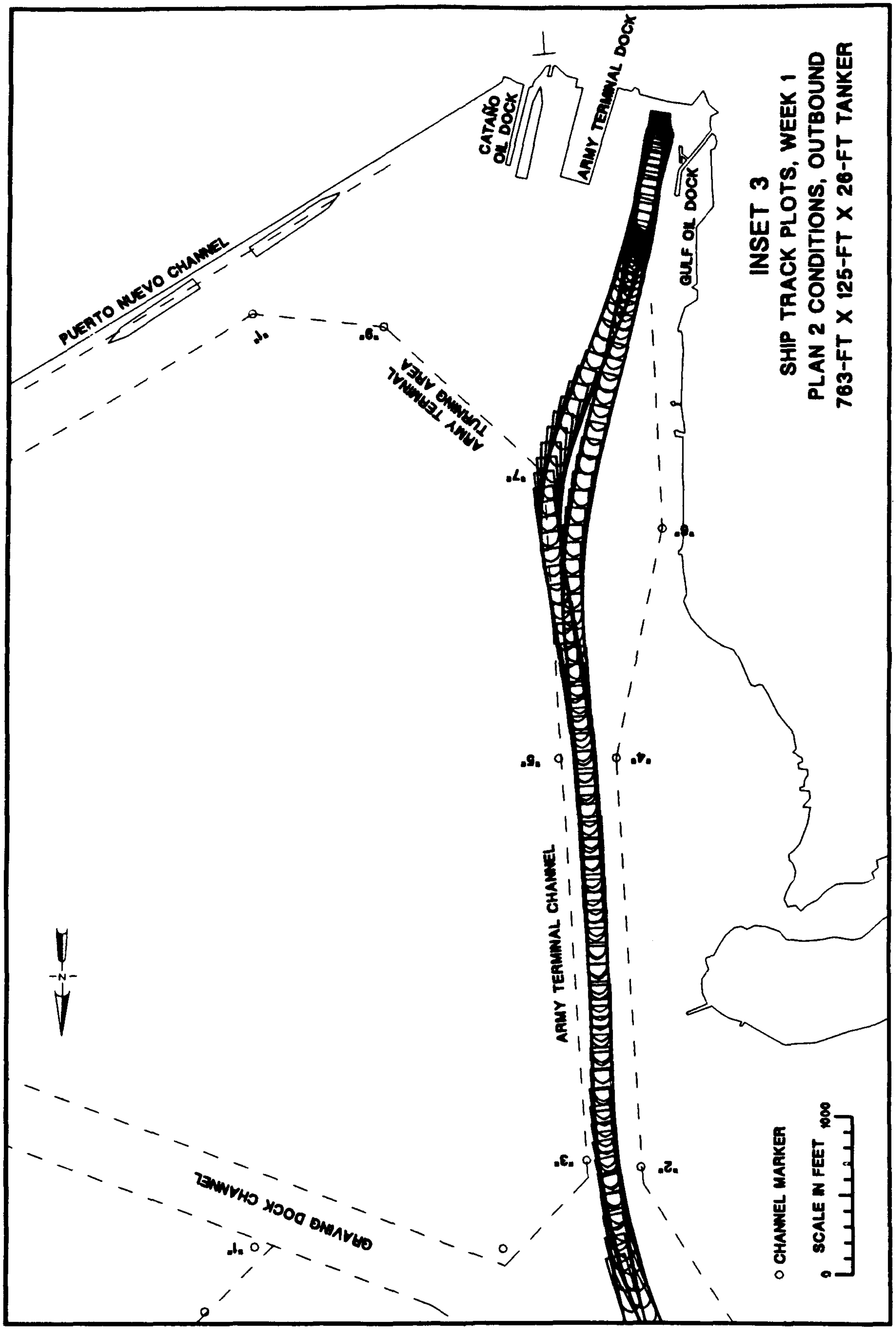


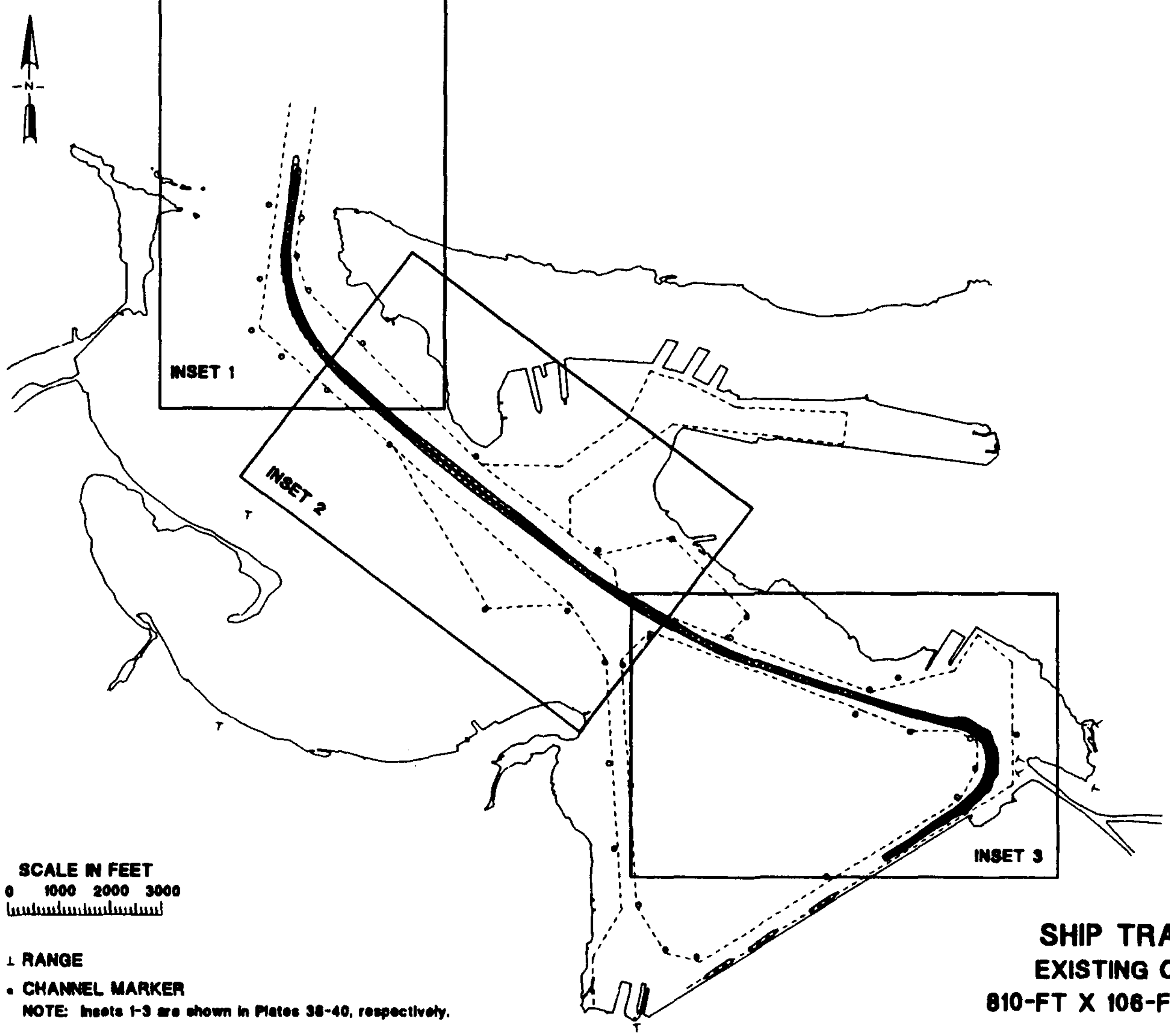
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER



INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

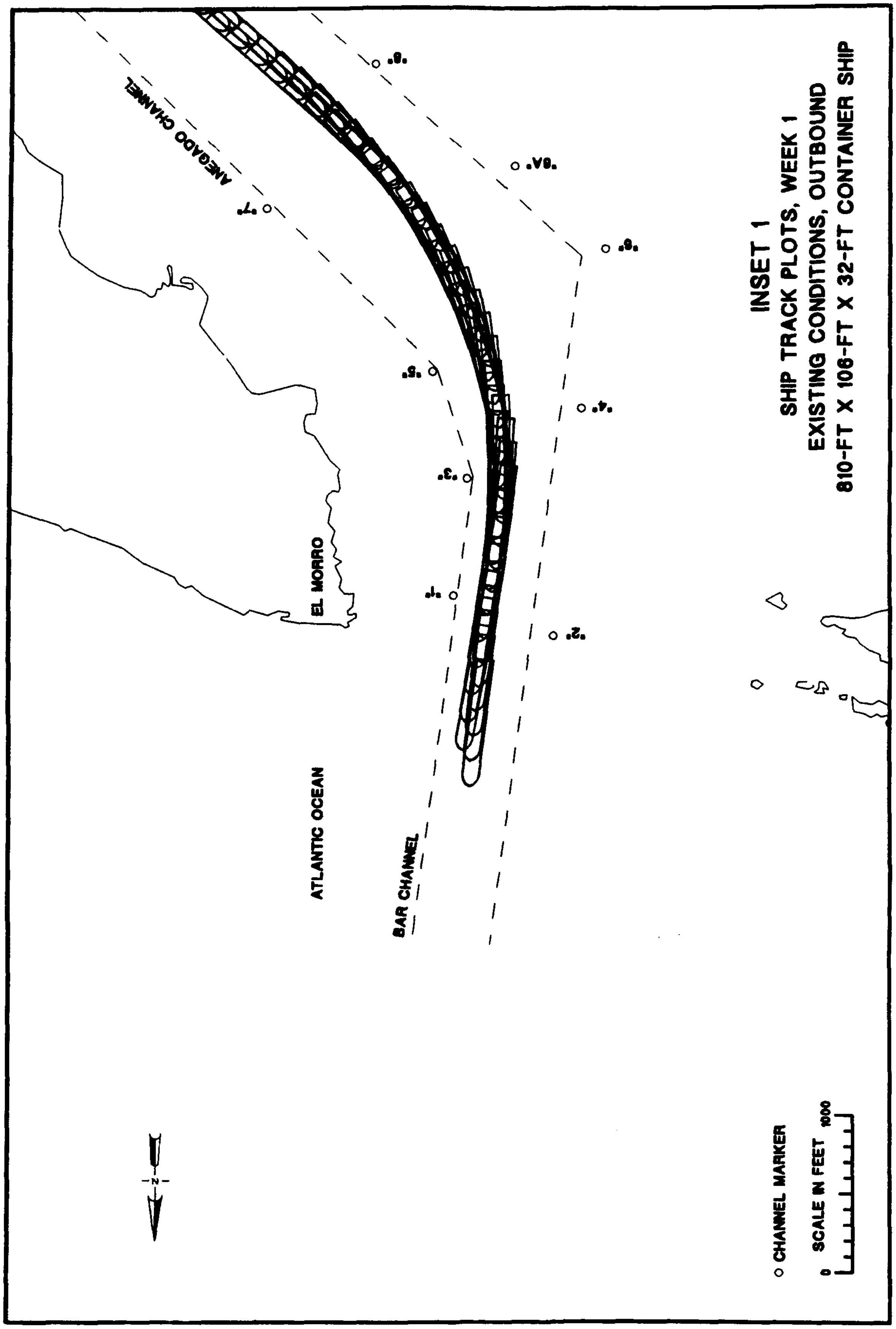

INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

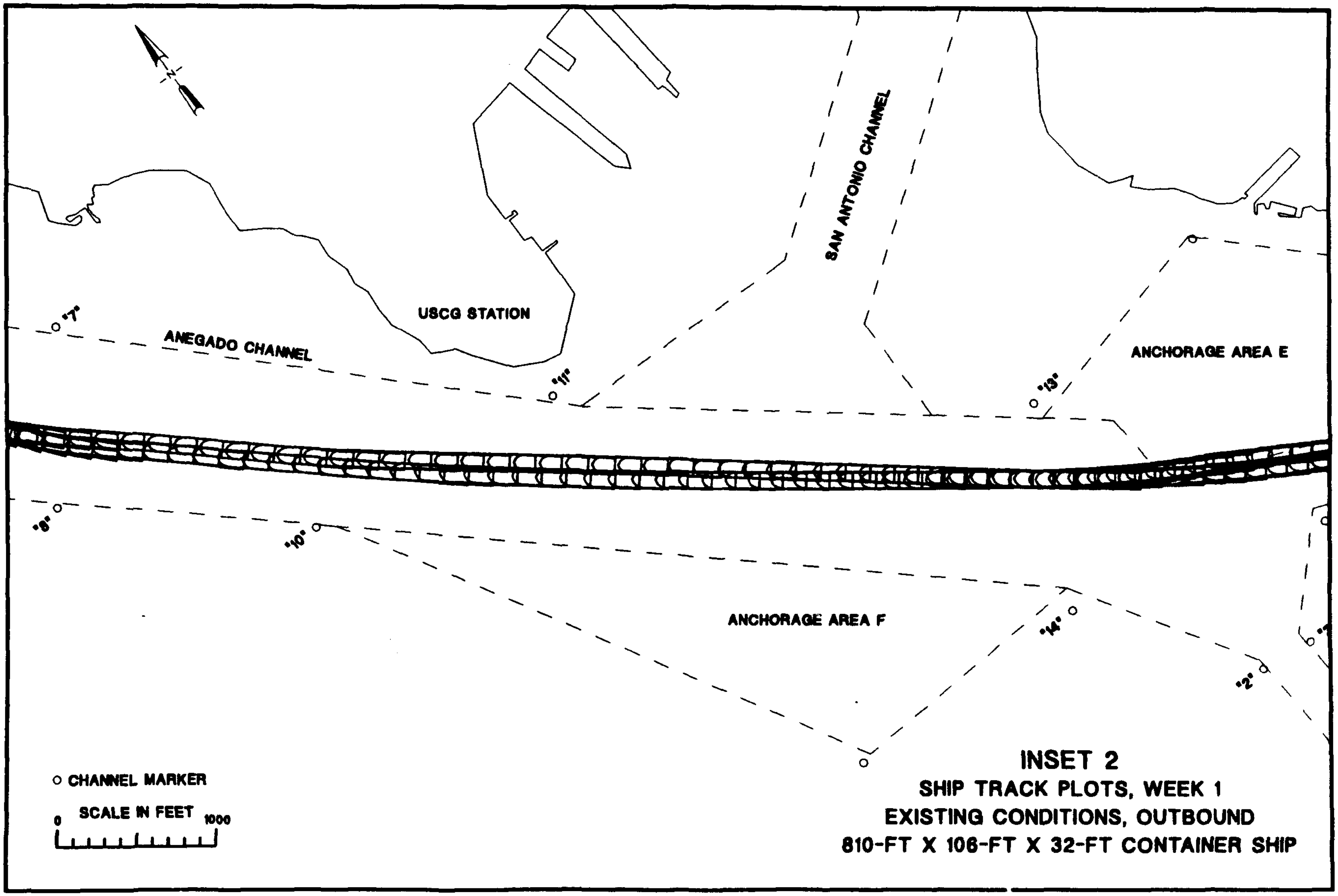

INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000



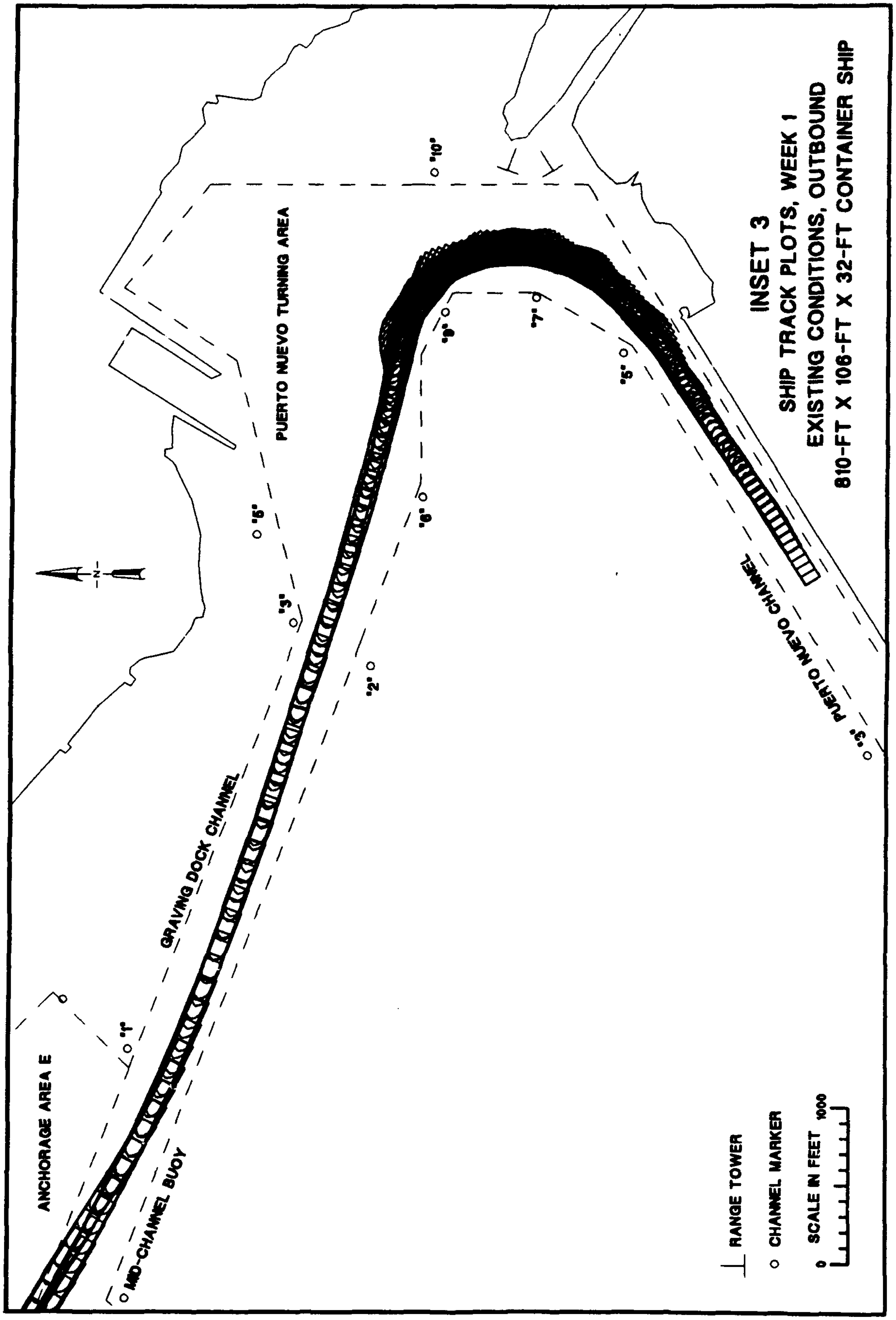
NOTE: Insets 1-3 are shown in Plates 38-40, respectively.

SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

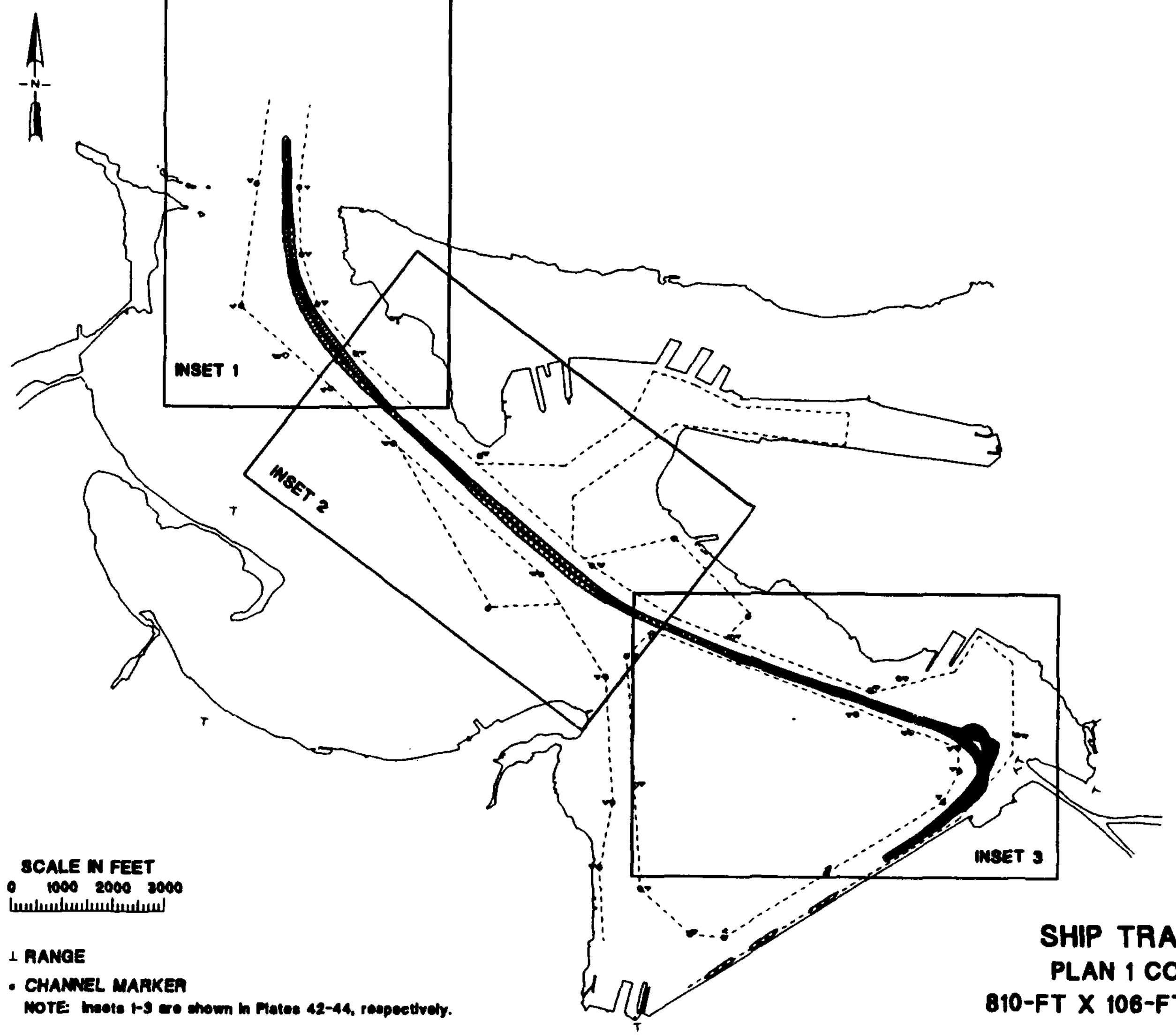

INSET 1
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
1
2
3
4
5
6
6A
7
8
N
CHANNEL MARKER
SCALE IN FEET
0
1000



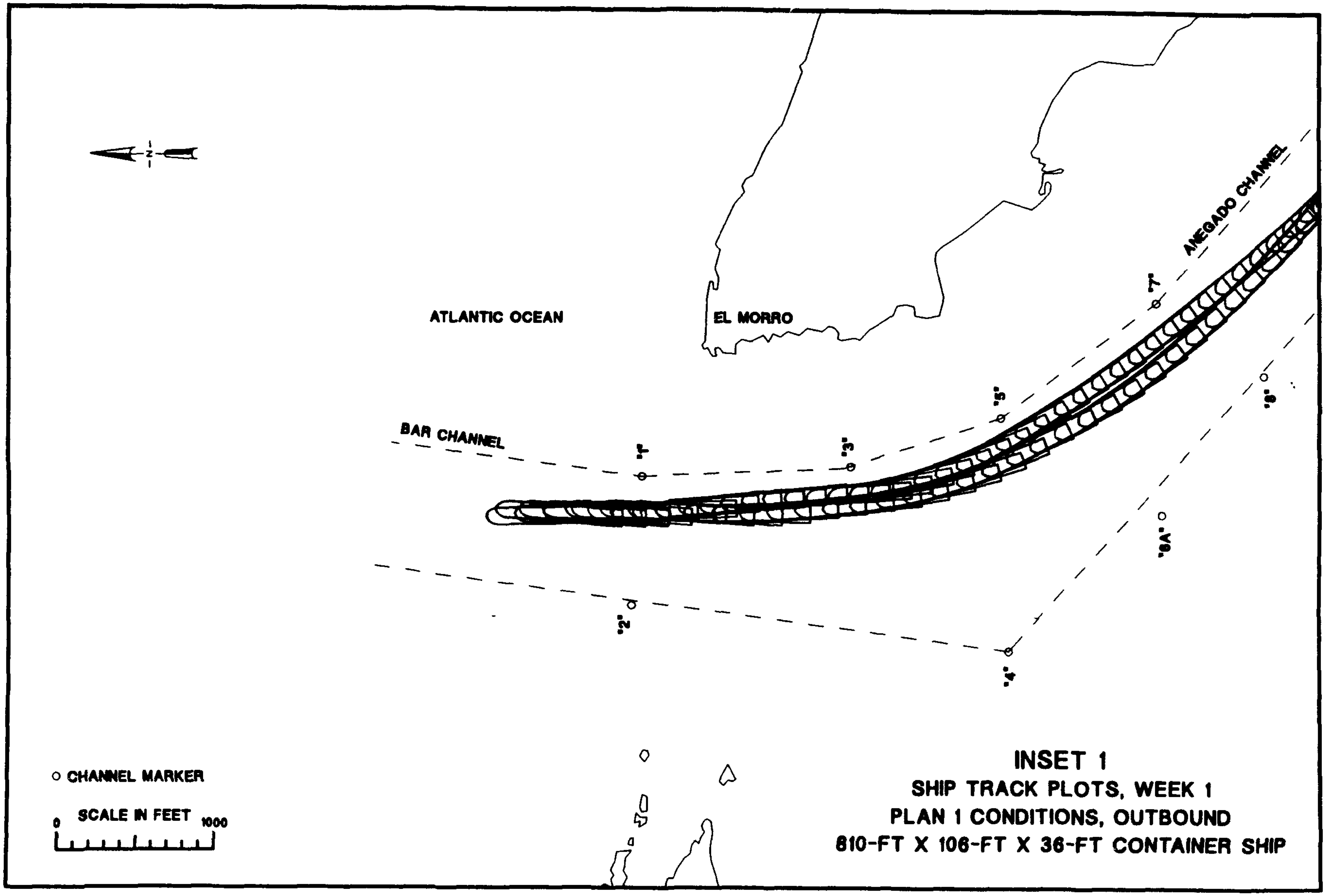
INSET 2
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP



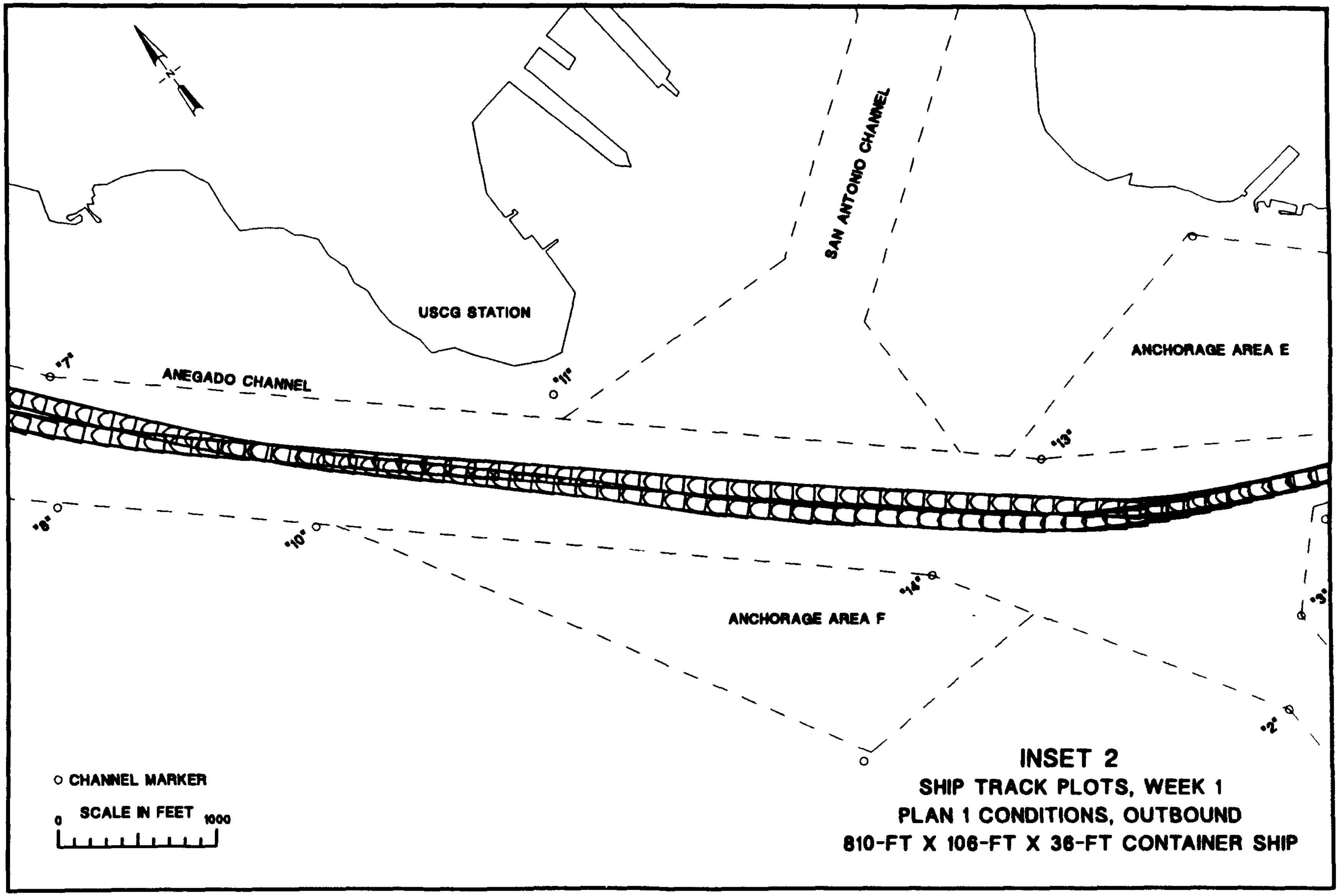
INSET 3
SHIP TRACK PLOTS, WEEK 1
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

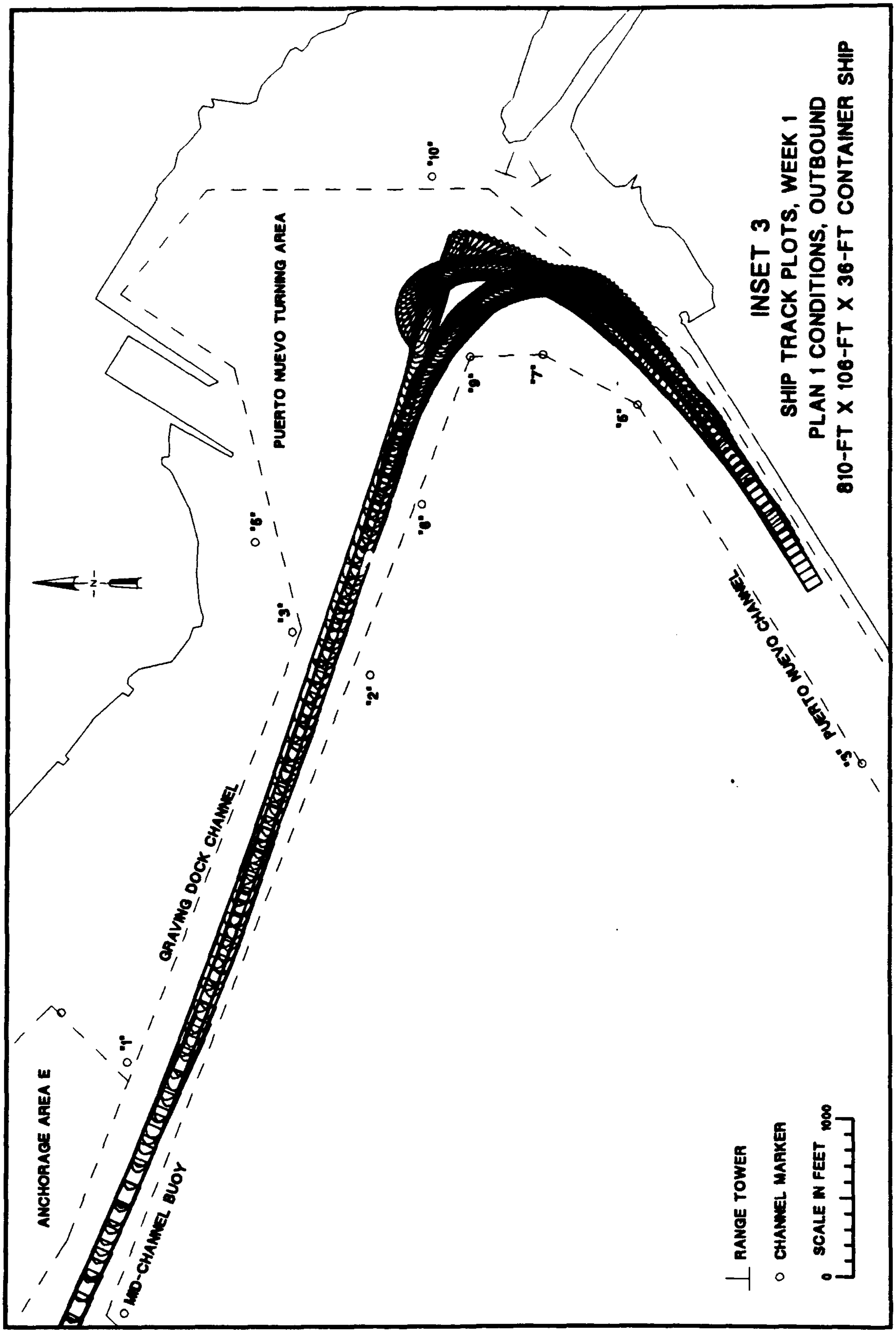


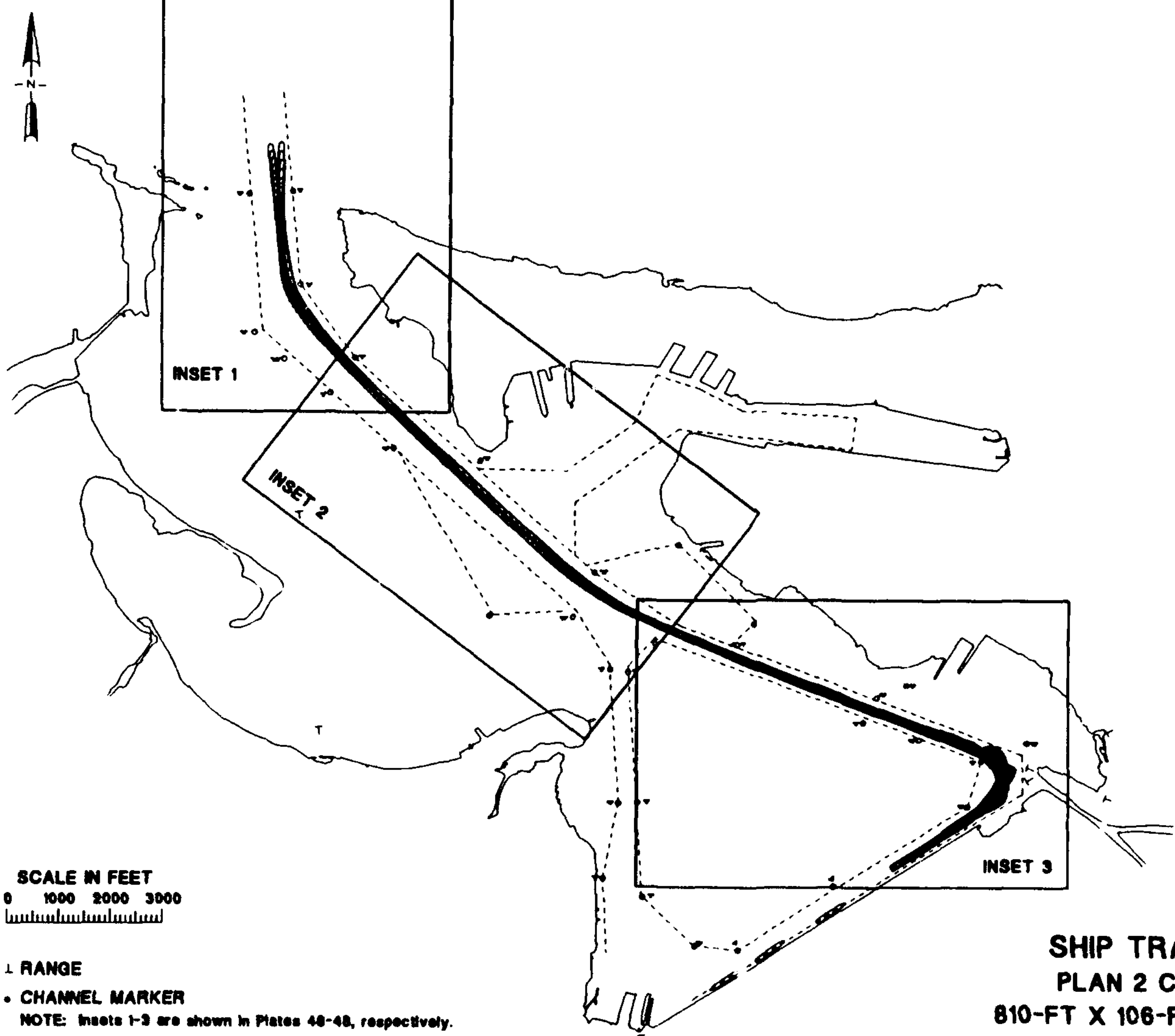
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP


USCG STATION
SAN ANTONIO CHANNEL
ANCHORAGE AREA E
ANEGADO CHANNEL
ANCHORAGE AREA F
"7"
"8"
"10"
"11"
"13"
"14"
"2"
"3"
N
CHANNEL MARKER
SCALE IN FEET
0
1000
INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP


INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO TURNING AREA
GRAVING DOCK CHANNEL
PUERTO NUEVO CHANNEL
ANCHORAGE AREA E
MID-CHANNEL BUOY
N
"1"
"2"
"3"
"5"
"6"
"7"
"8"
"9"
"10"
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000



SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

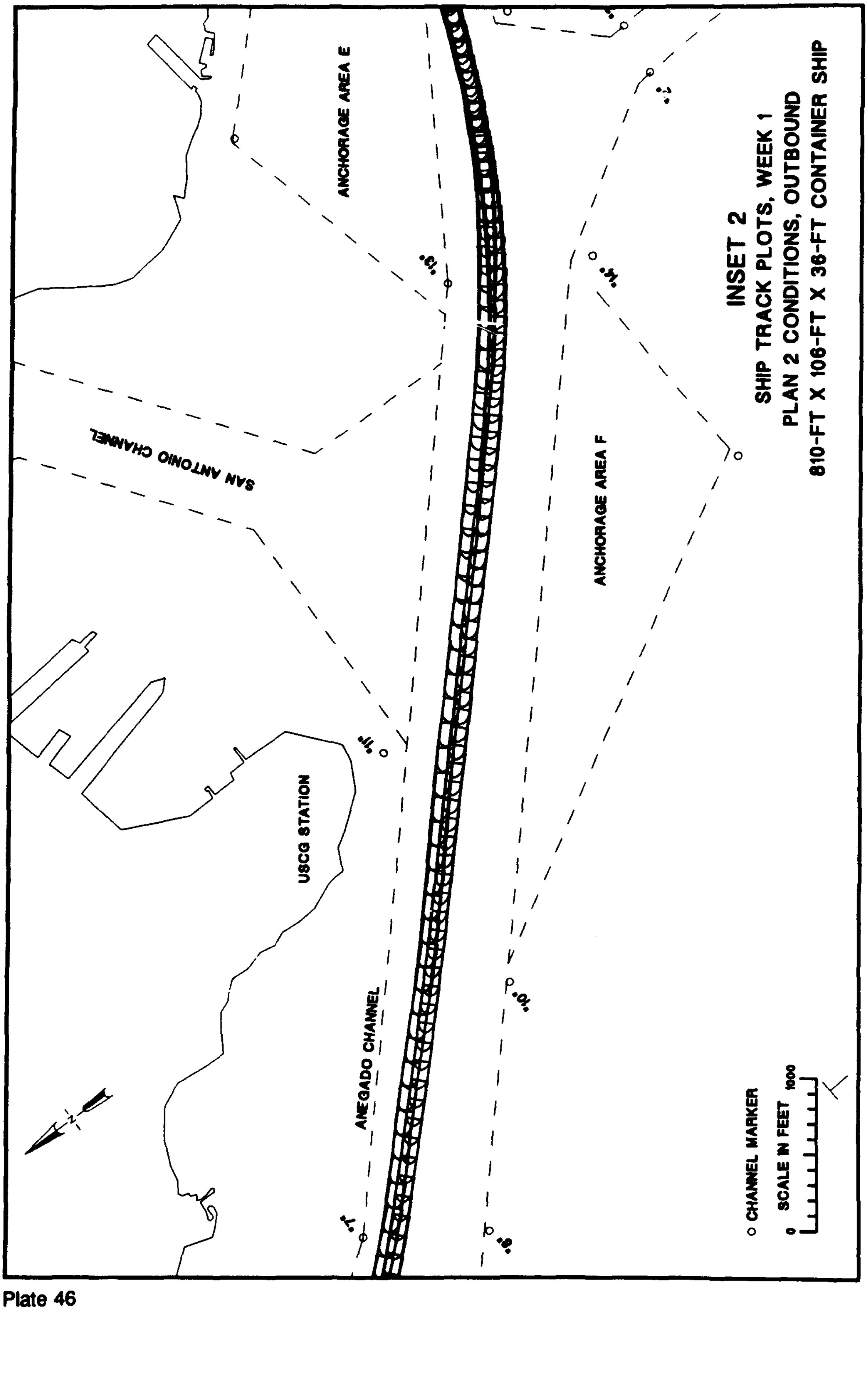
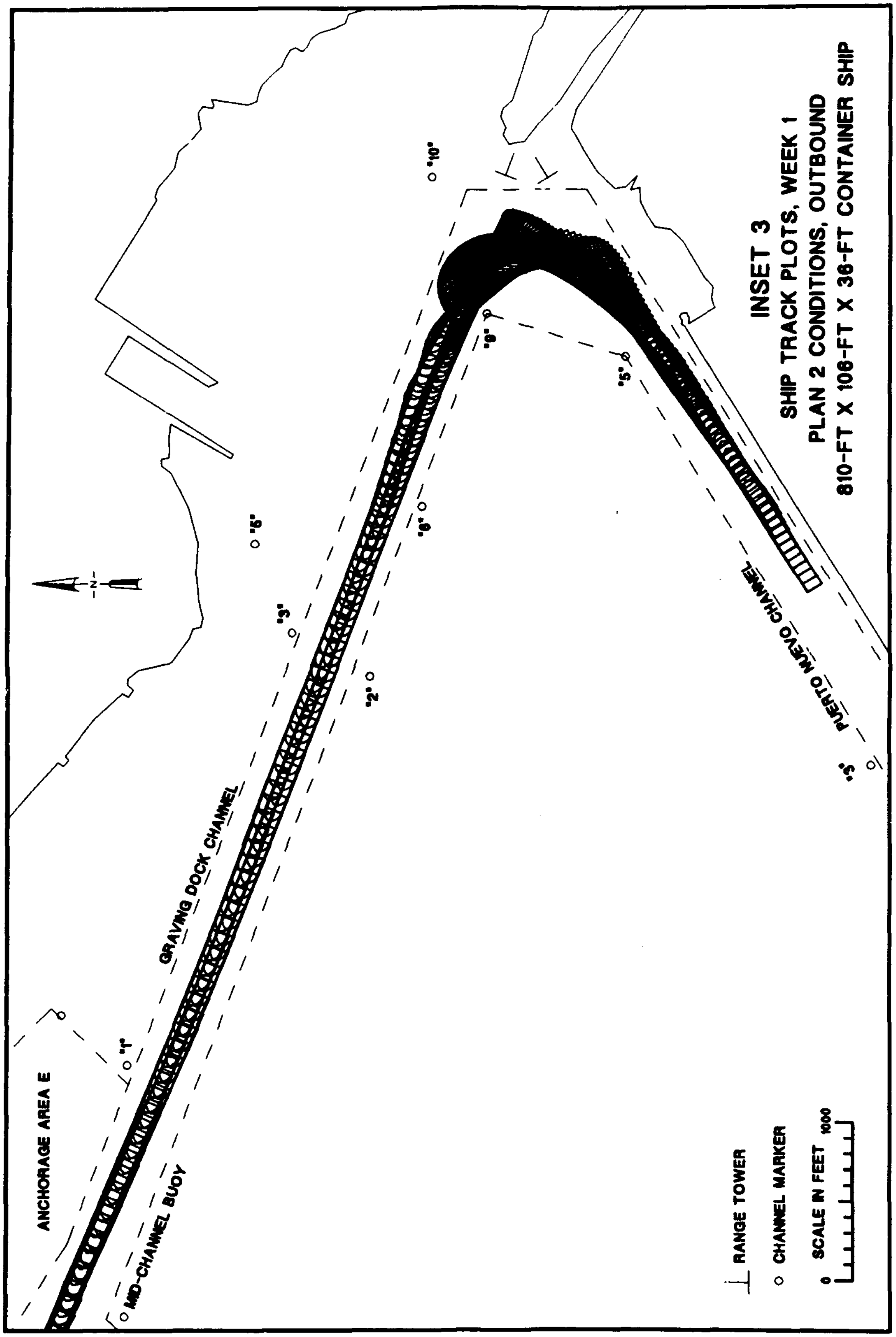
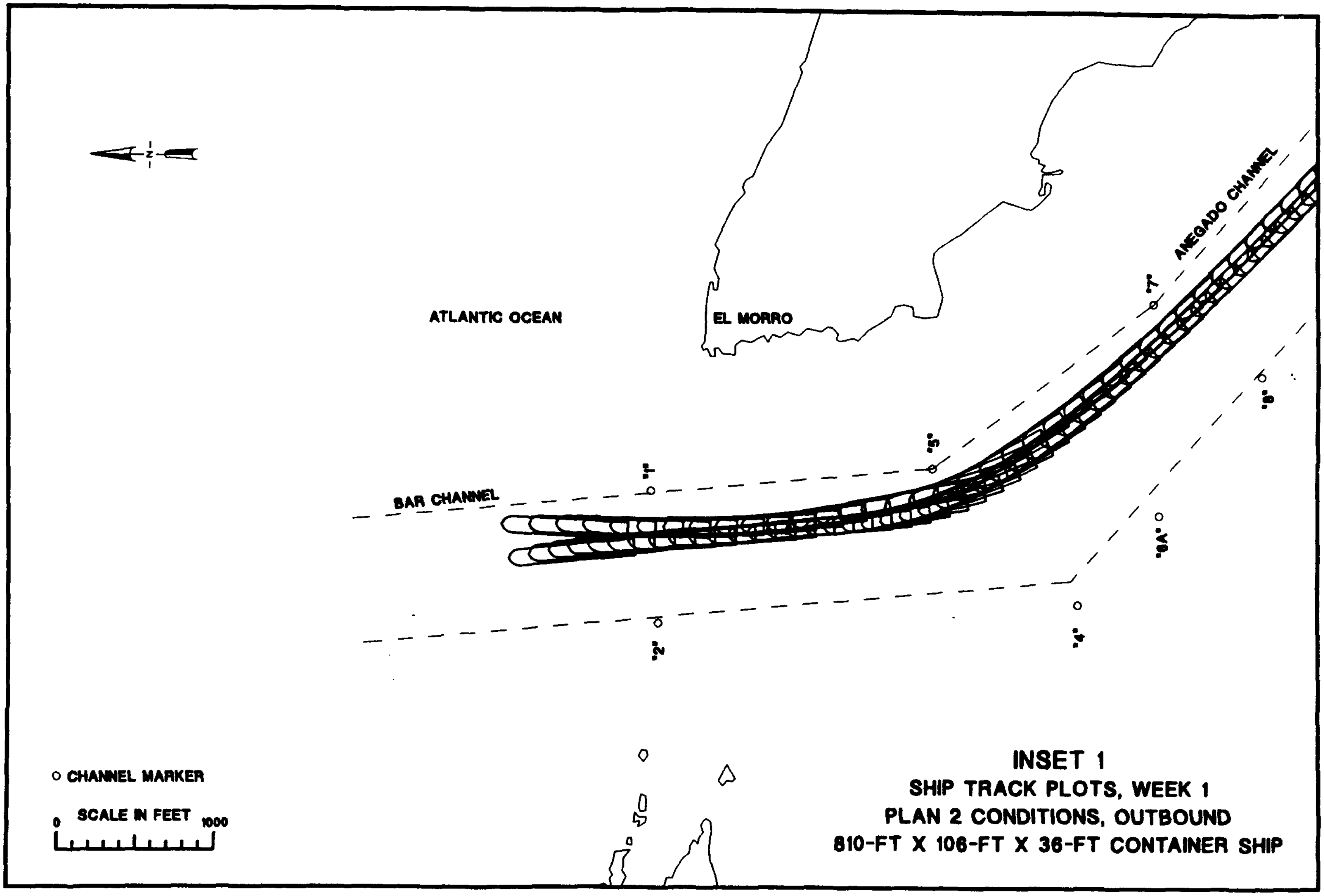

INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANCHORAGE AREA E
ANCHORAGE AREA F
SAN ANTONIO CHANNEL
USCG STATION
ANEGADO CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

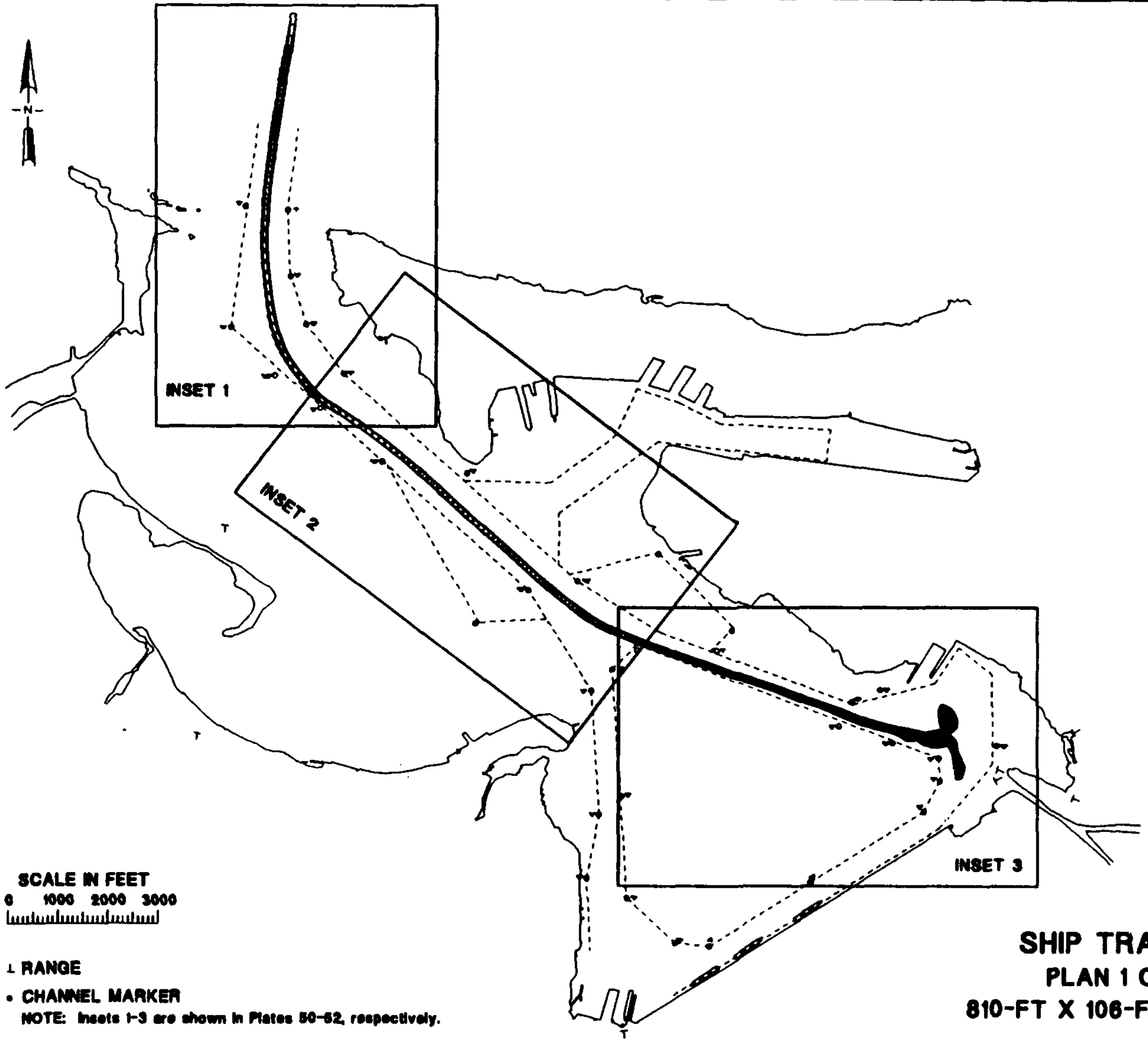
Plate 46



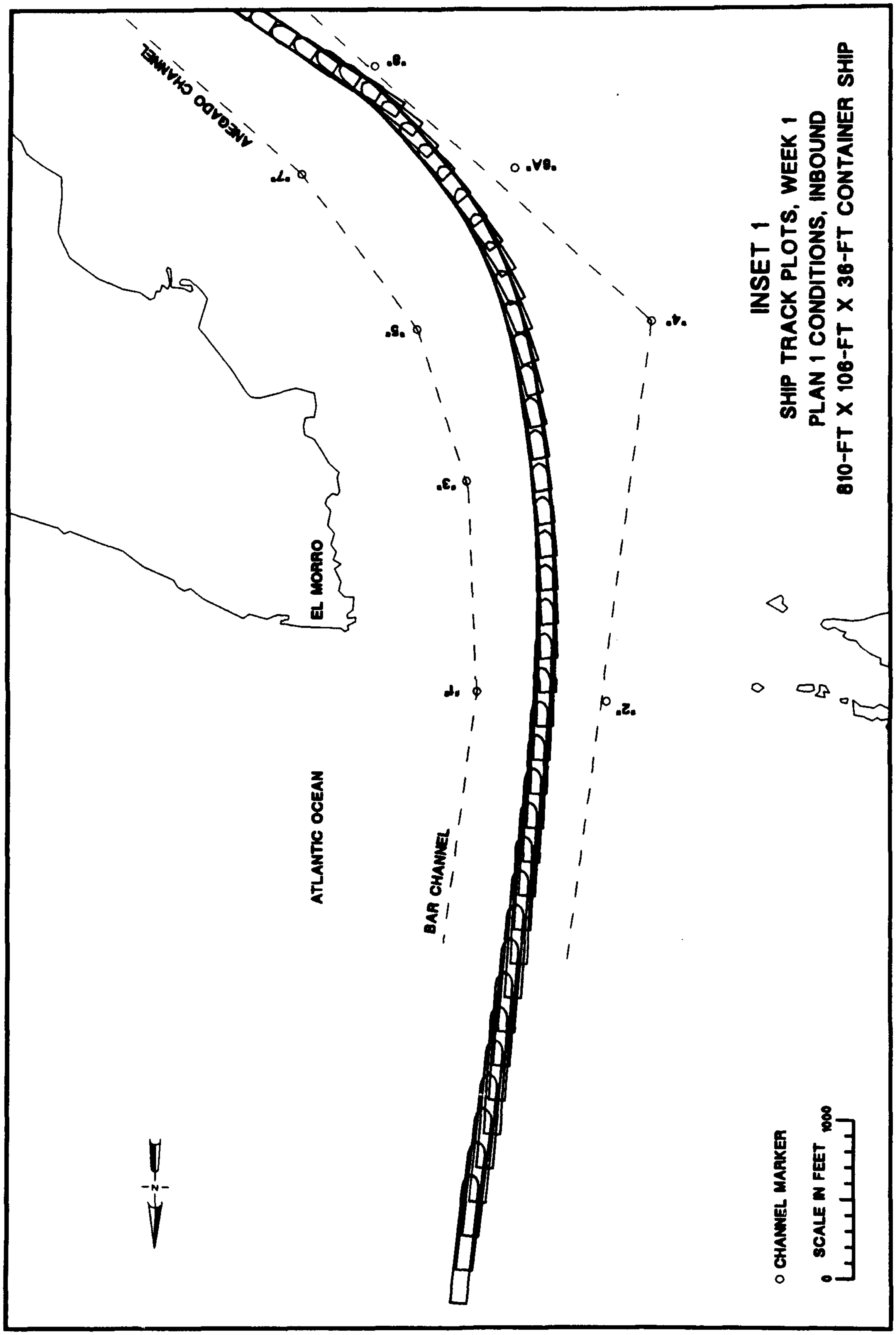
INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



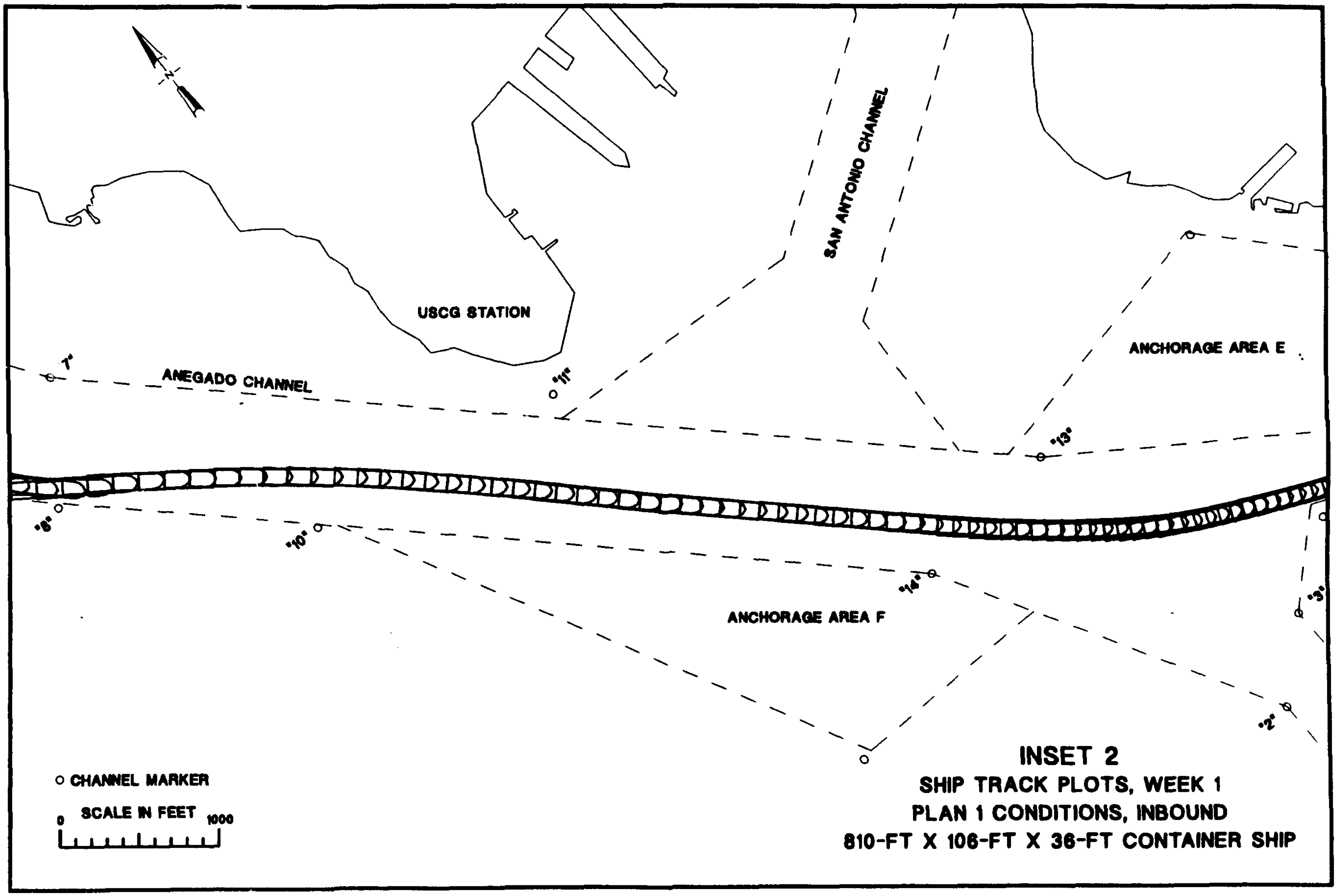
ATLANTIC OCEAN
EL MORRO
ANEGADO CHANNEL
BAR CHANNEL
"1"
"2"
"4"
"5"
"7"
"8"
"8A"
N
○ CHANNEL MARKER
SCALE IN FEET
0
1000
INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 2 CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



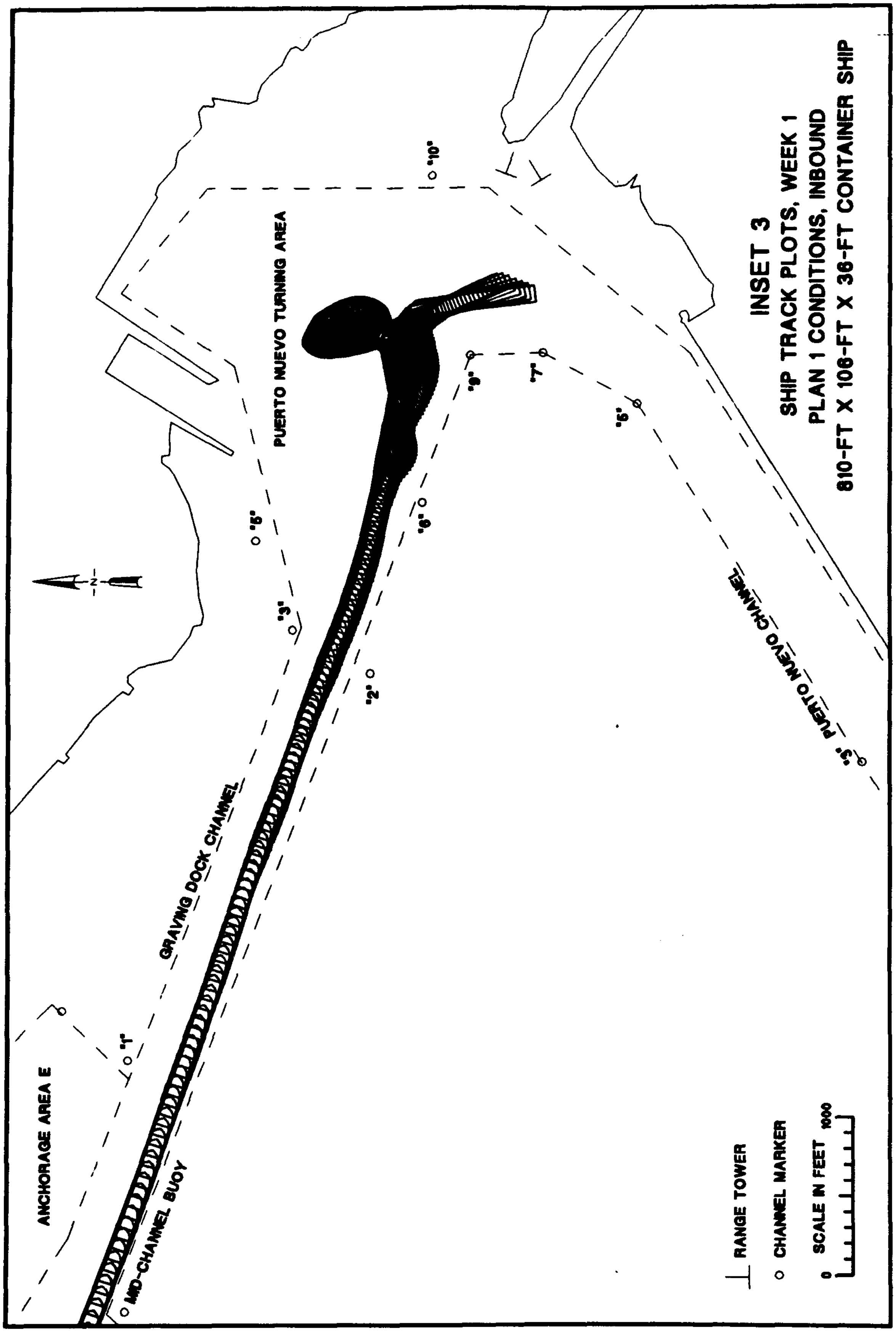
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

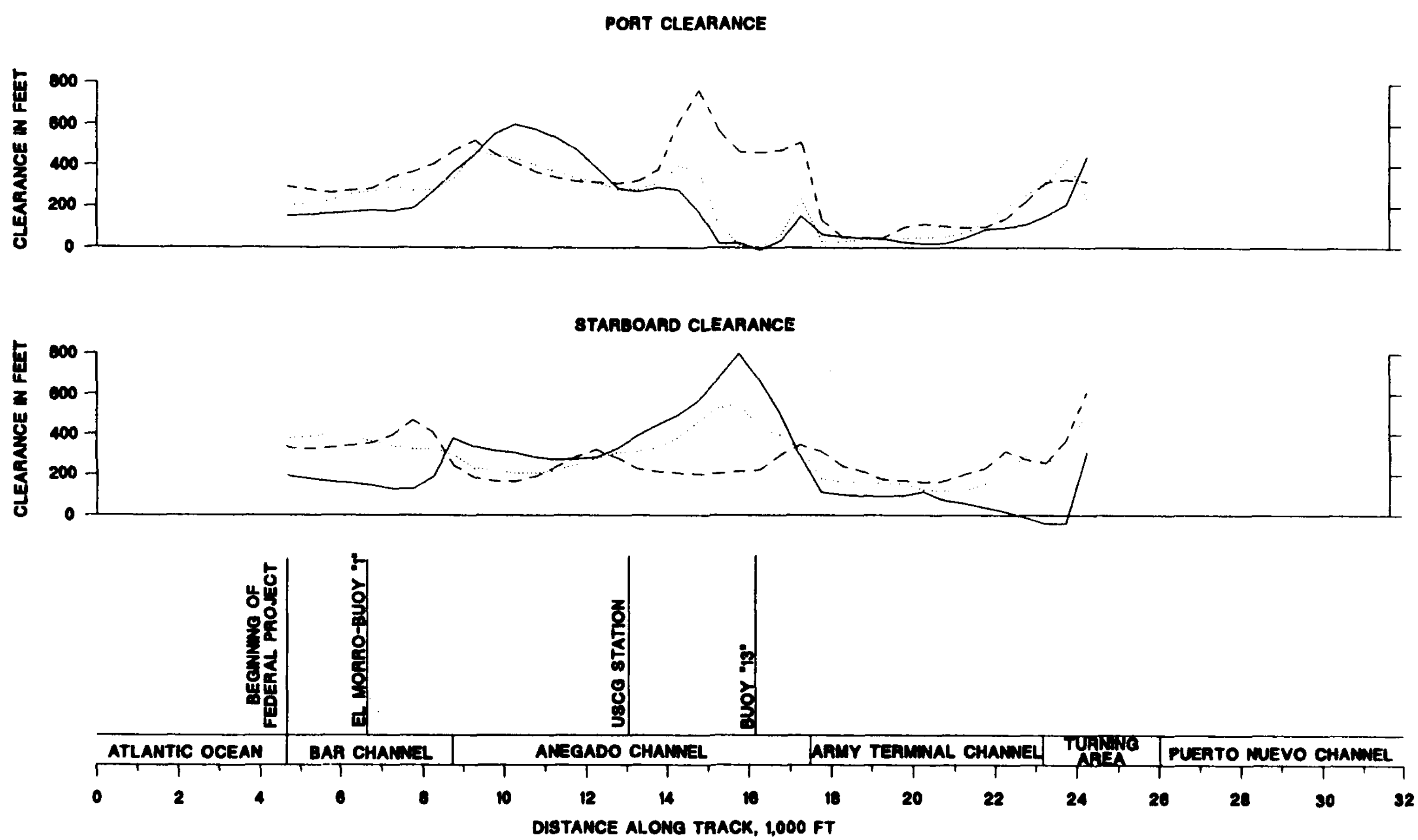


INSET 1
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 2
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP


INSET 3
SHIP TRACK PLOTS, WEEK 1
PLAN 1 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO TURNING AREA
GRAVING DOCK CHANNEL
PUERTO NUEVO CHANNEL
ANCHORAGE AREA E
MID-CHANNEL BUOY
N
"1"
"2"
"3"
"5"
"6"
"8"
"7"
"5"
"3"
"10"
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000

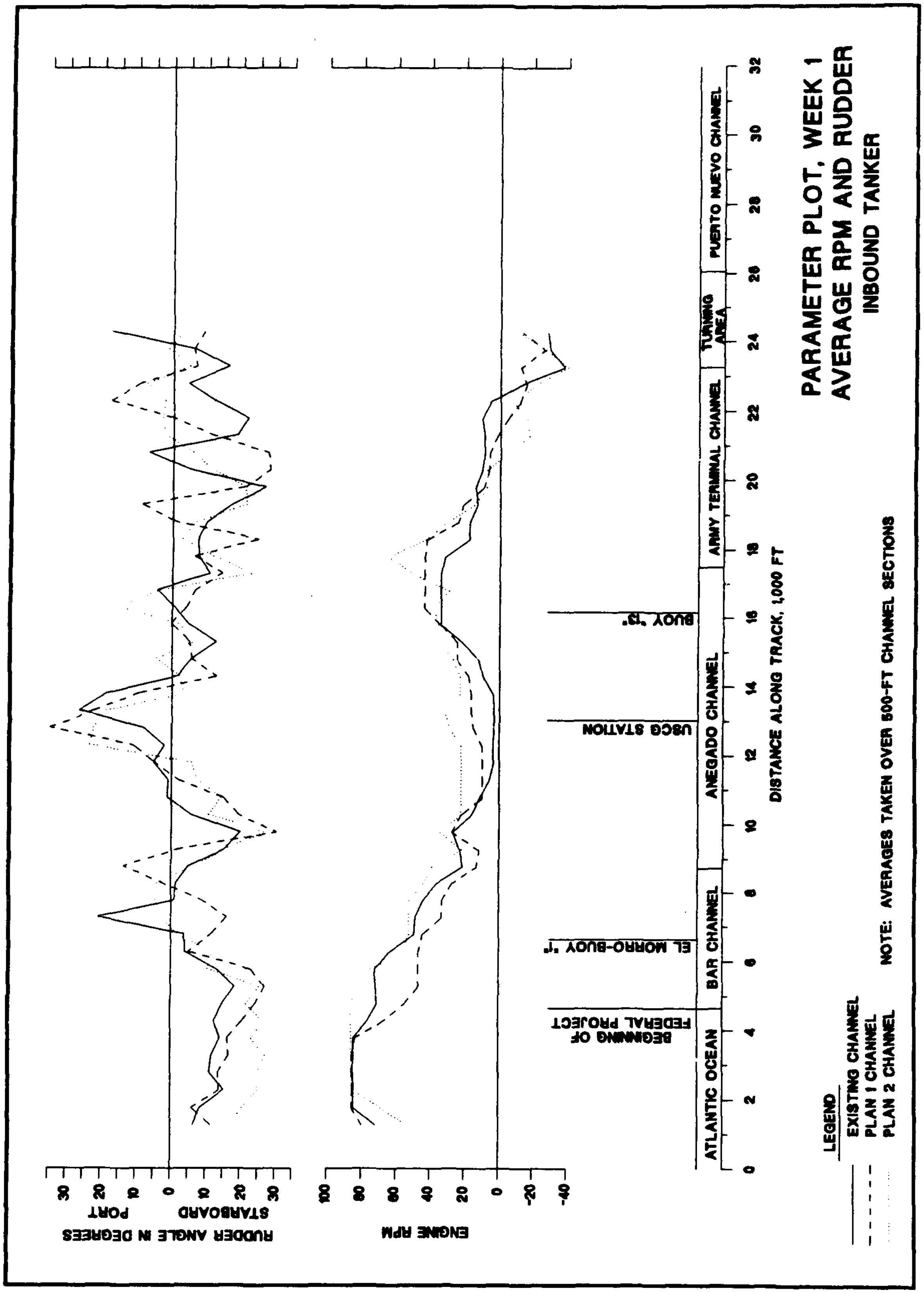


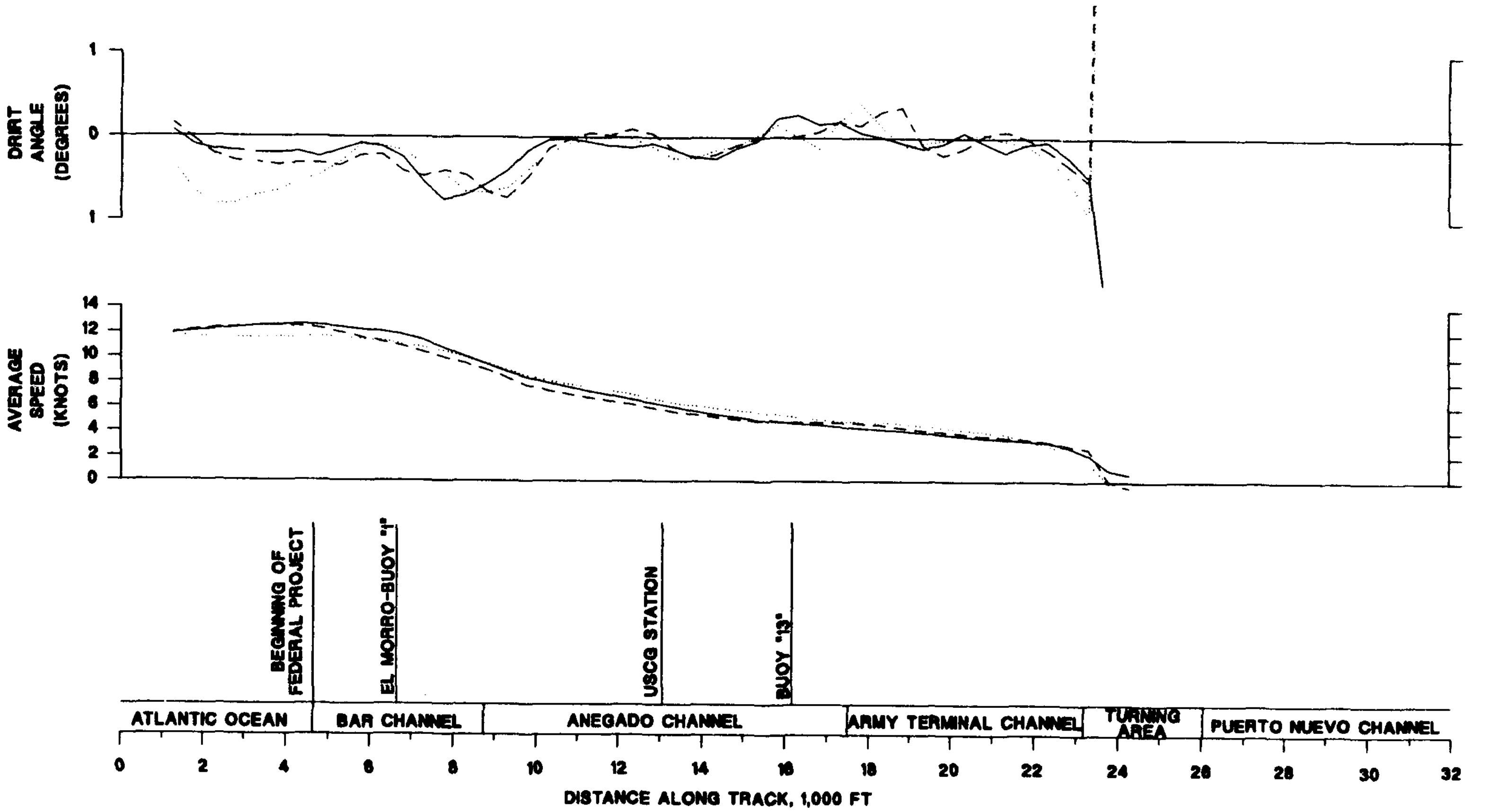
LEGEND

- EXISTING CHANNEL
- PLAN 1 CHANNEL
- PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOT, WEEK 1
AVERAGE MINIMUM CLEARANCE
INBOUND TANKER

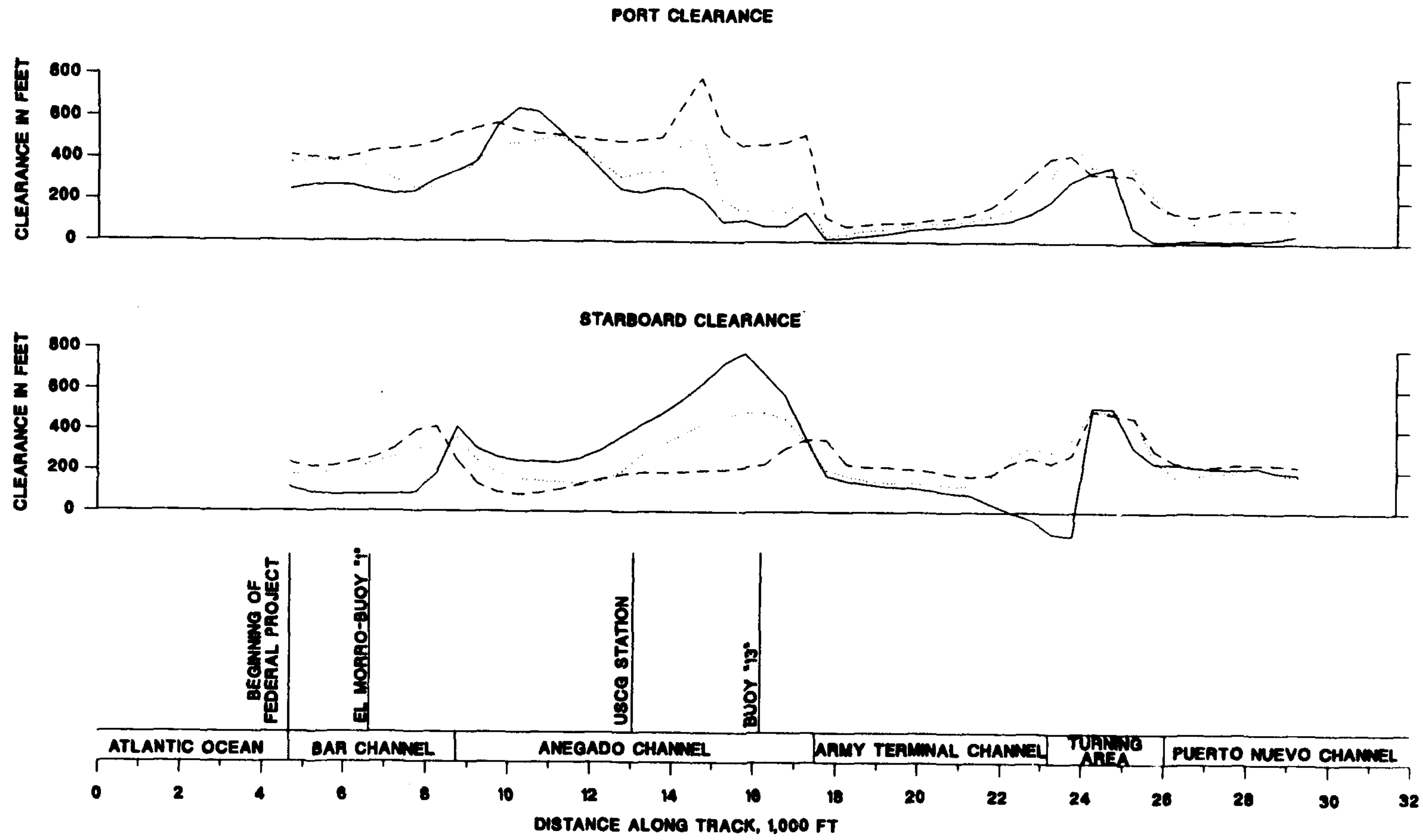

PARAMETER PLOT, WEEK 1
AVERAGE RPM AND RUDDER
INBOUND TANKER
RUDDER ANGLE IN DEGREES
PORT
STARBOARD
ENGINE RPM
DISTANCE ALONG TRACK, 1,000 FT
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
ARMY TERMINAL CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "I"
USCG STATION
BUOY "13"
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS



LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOT, WEEK 1
AVERAGE SPEED AND DRIFT ANGLE
INBOUND TANKER

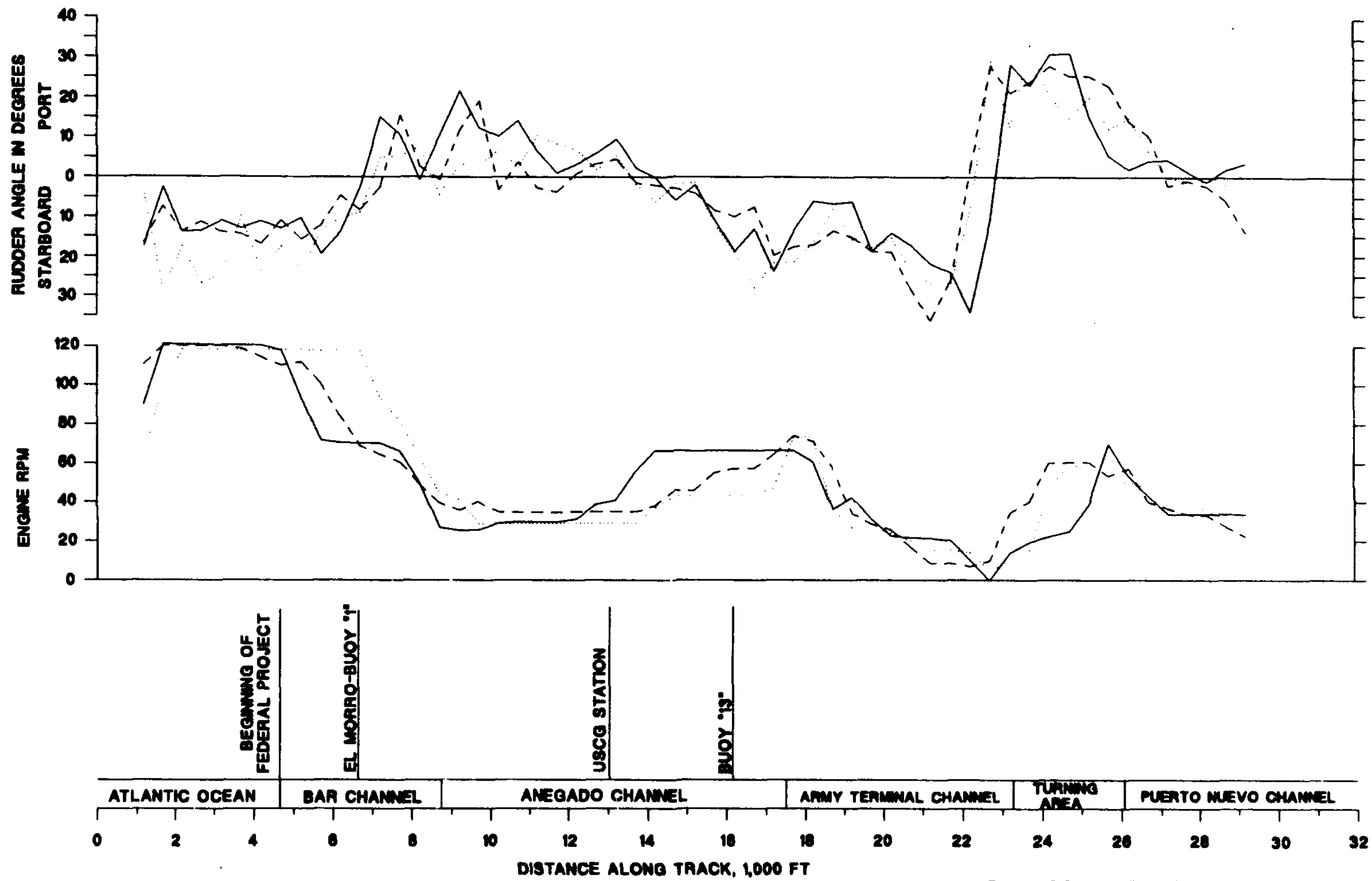


LEGEND

EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOT, WEEK 1
AVERAGE MINIMUM CLEARANCE
INBOUND CONTAINER SHIP



LEGEND

EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOT, WEEK 1
AVERAGE RPM AND RUDDER
INBOUND CONTAINER SHIP

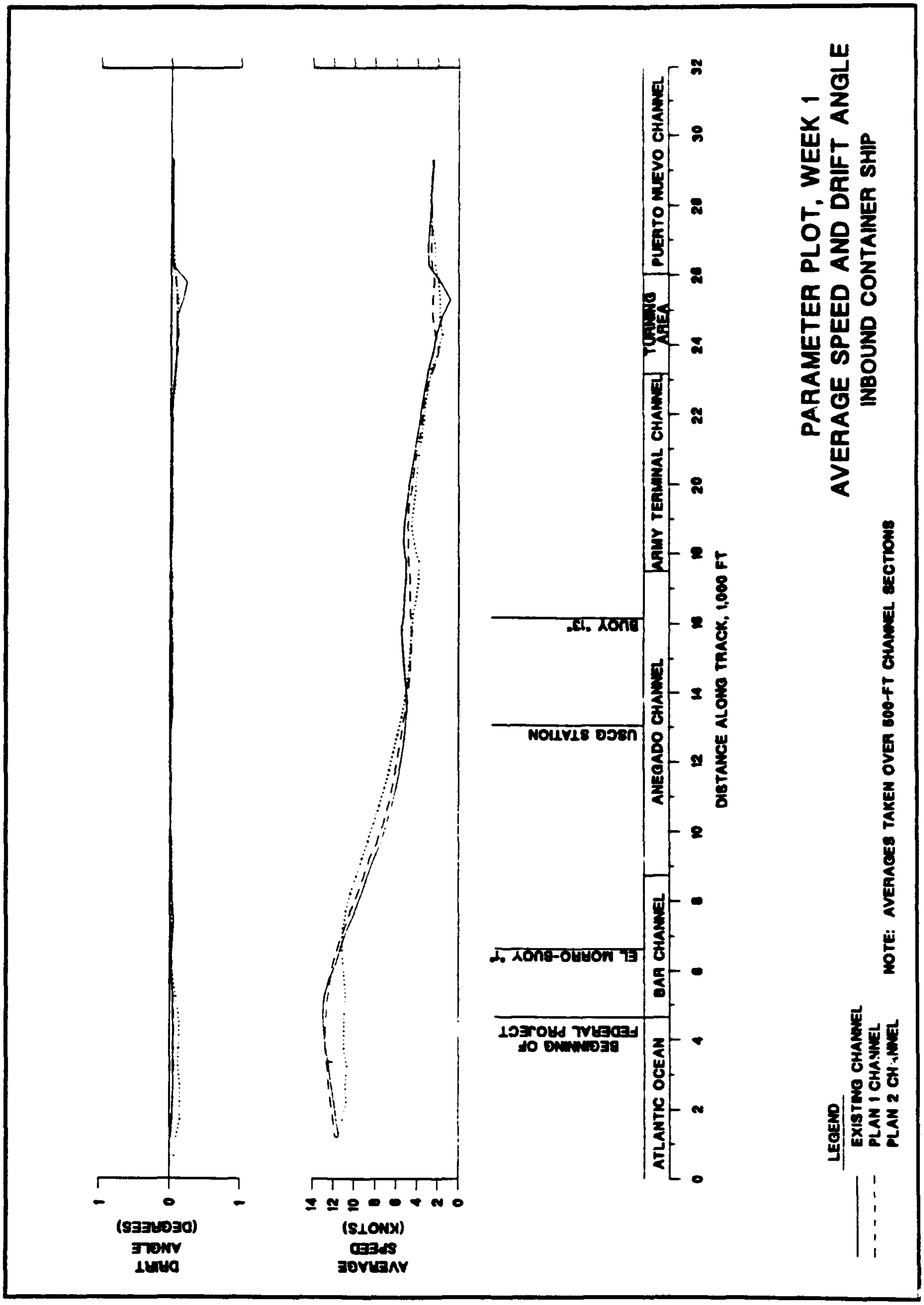
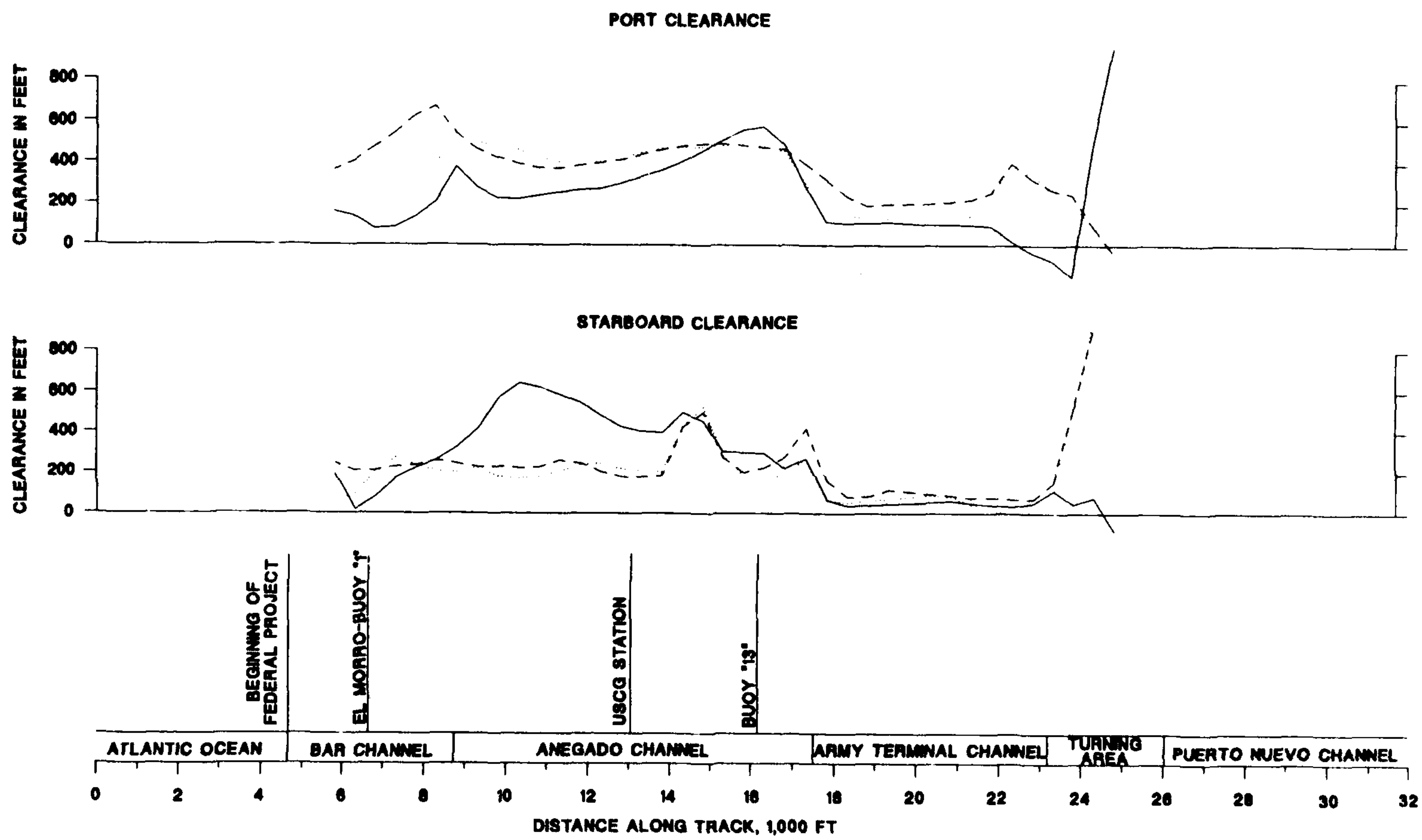

PARAMETER PLOT, WEEK 1
AVERAGE SPEED AND DRIFT ANGLE
INBOUND CONTAINER SHIP
DRIFT ANGLE (DEGREES)
AVERAGE SPEED (KNOTS)
DISTANCE ALONG TRACK, 1,000 FT
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
ARMY TERMINAL CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "1"
USCG STATION
BUOY "13"
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

Plate 58

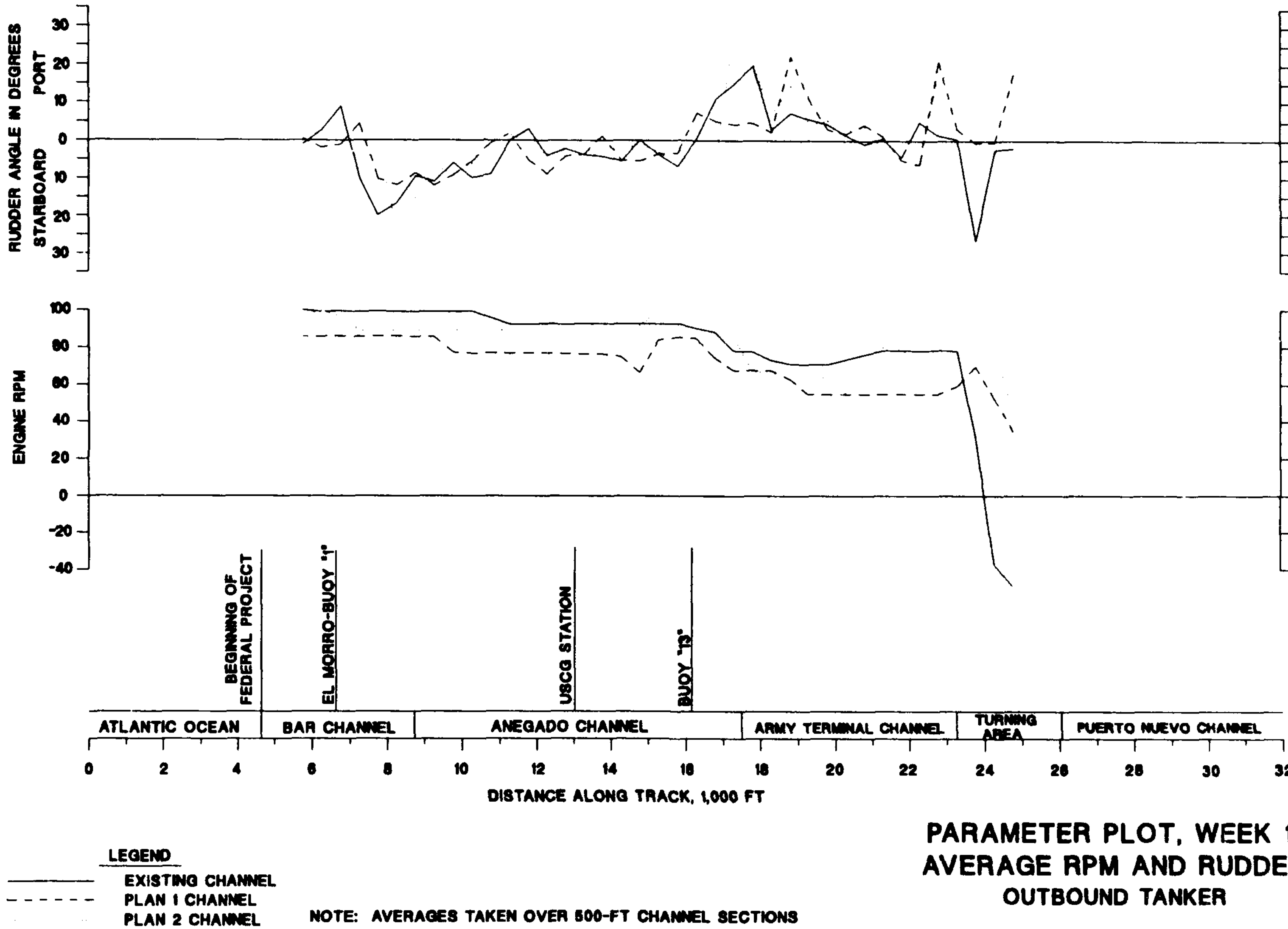


PARAMETER PLOT, WEEK 1
AVERAGE MINIMUM CLEARANCE
OUTBOUND TANKER

LEGEND

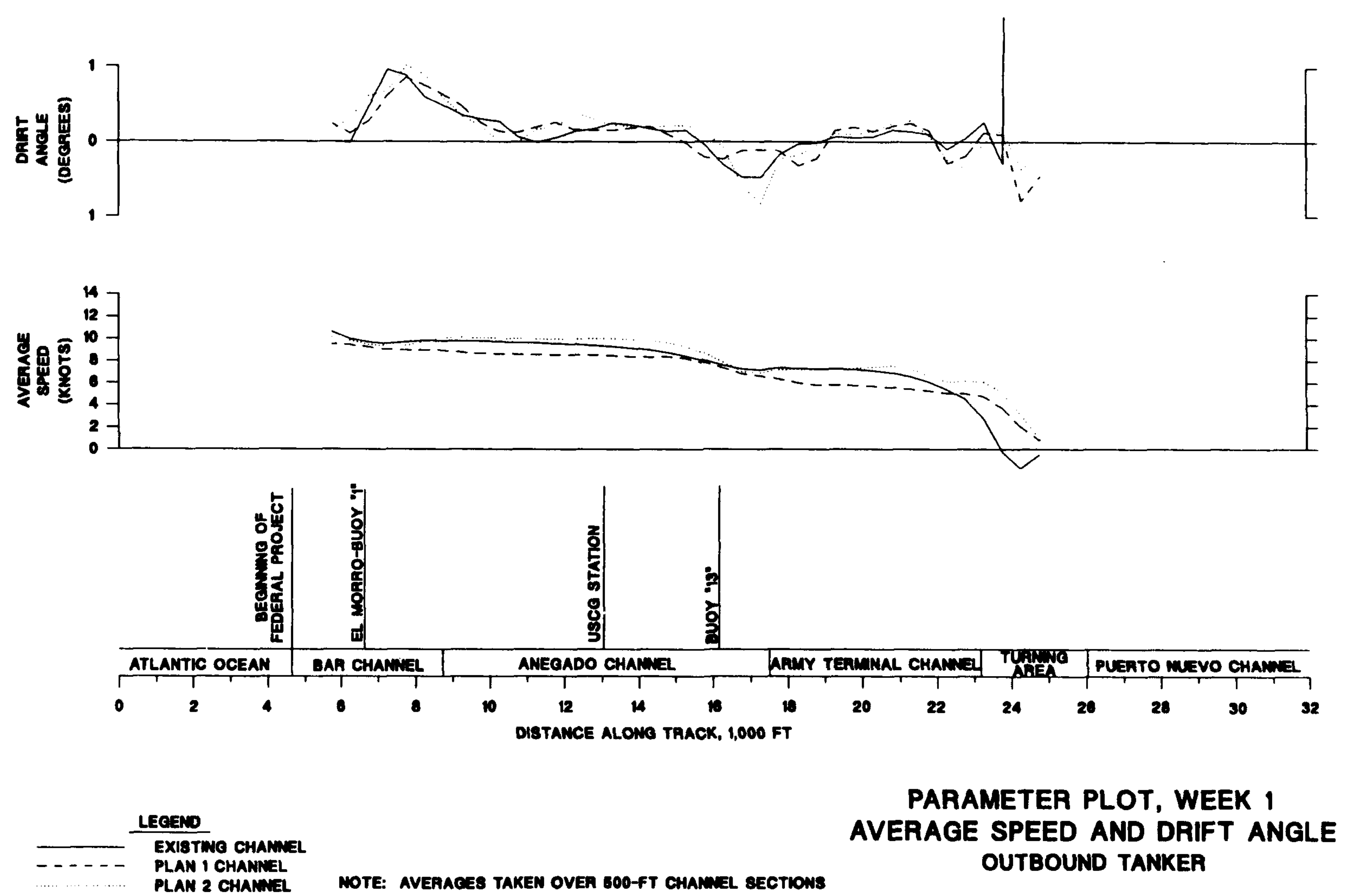
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

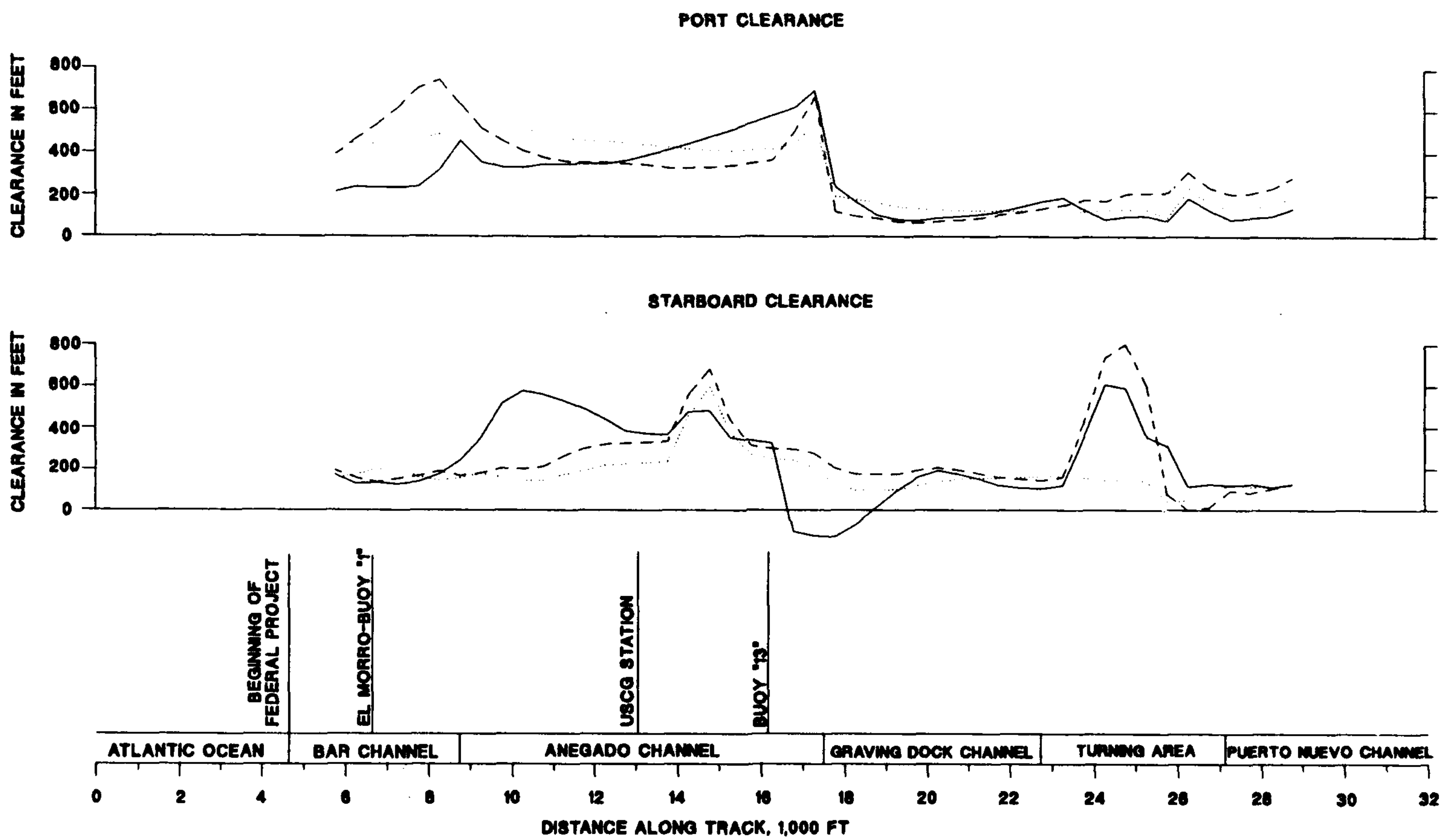


NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOT, WEEK 1
AVERAGE RPM AND RUDDER
OUTBOUND TANKER



PARAMETER PLOT, WEEK 1
AVERAGE SPEED AND DRIFT ANGLE
OUTBOUND TANKER

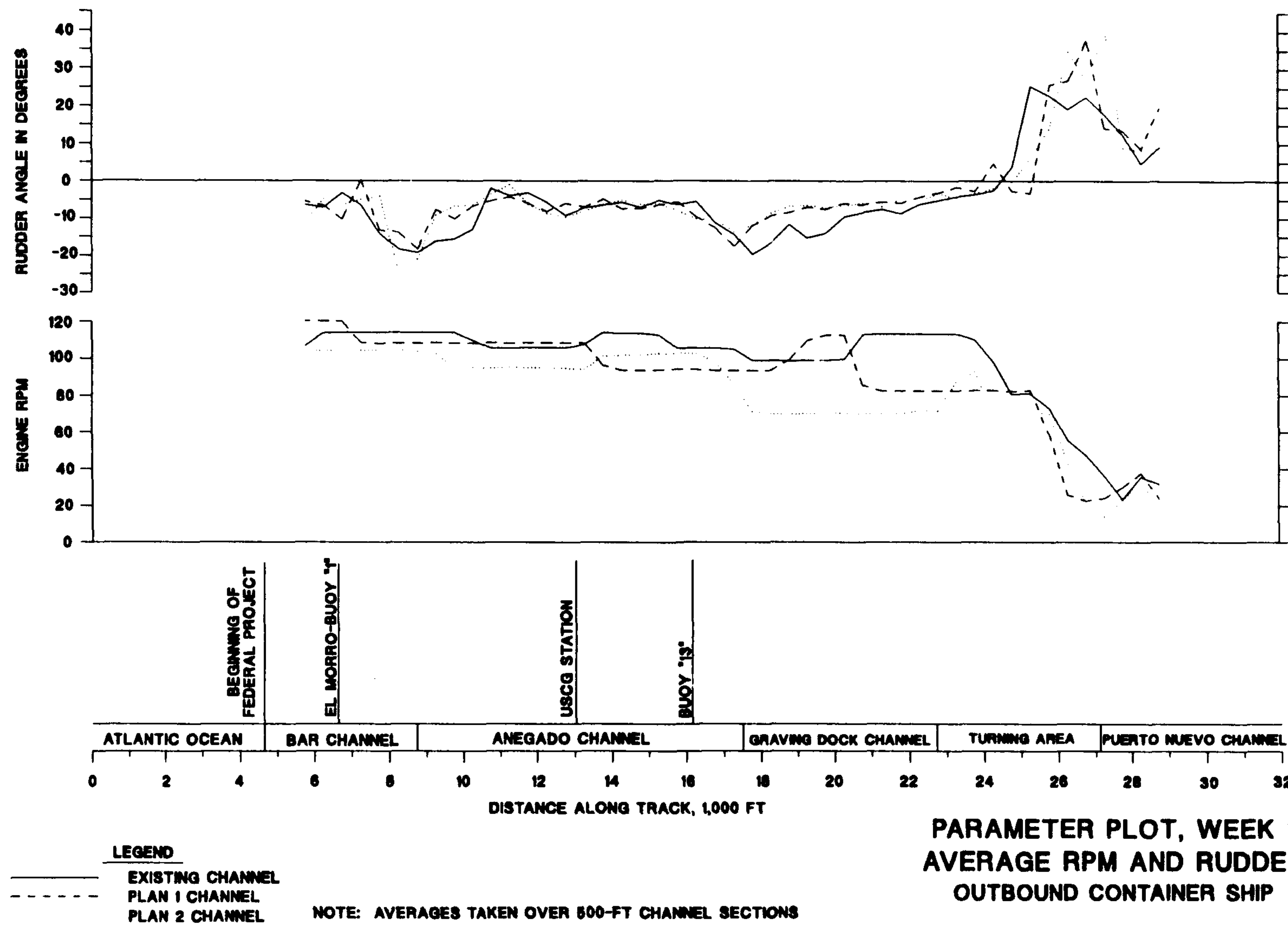


LEGEND

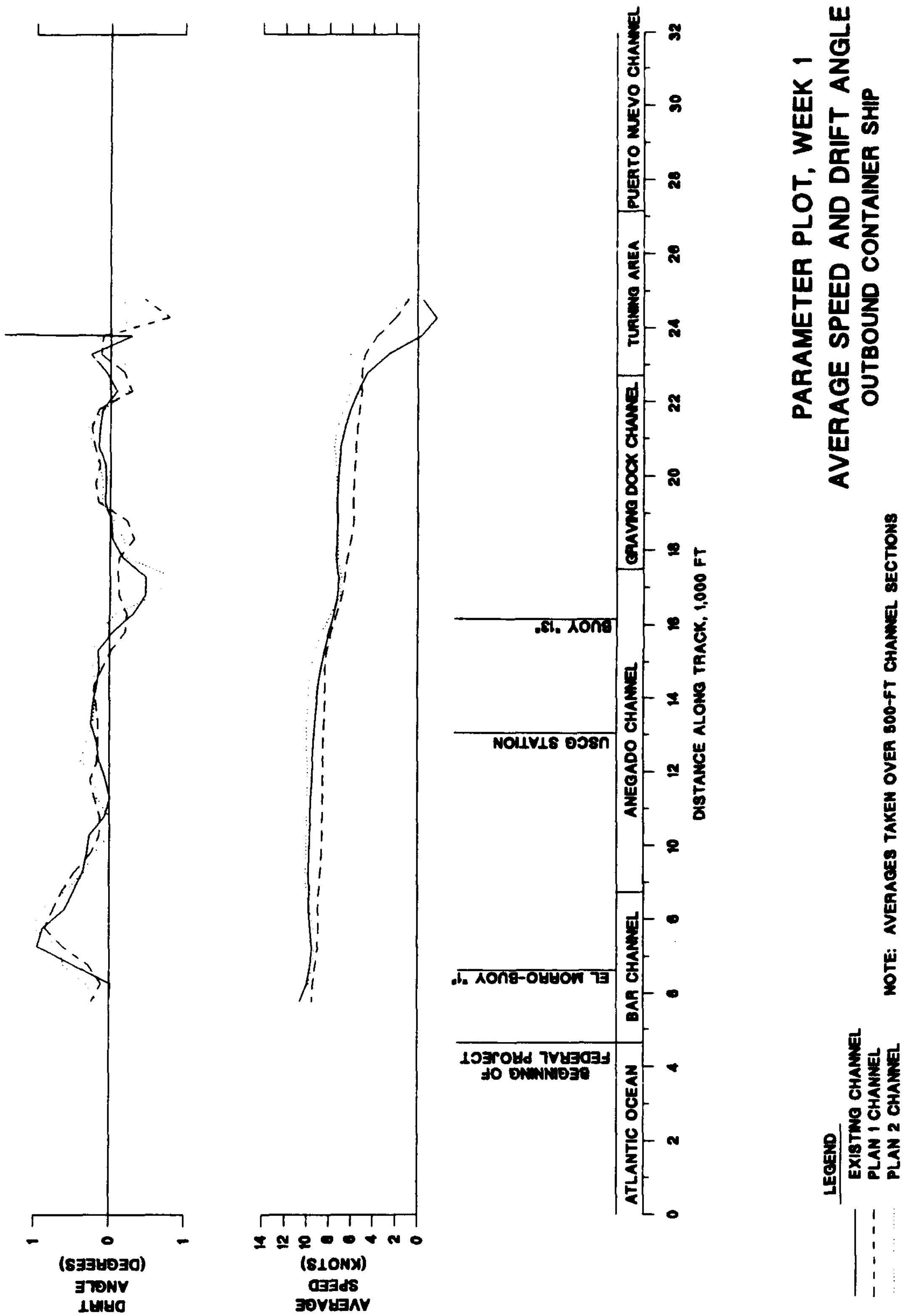
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

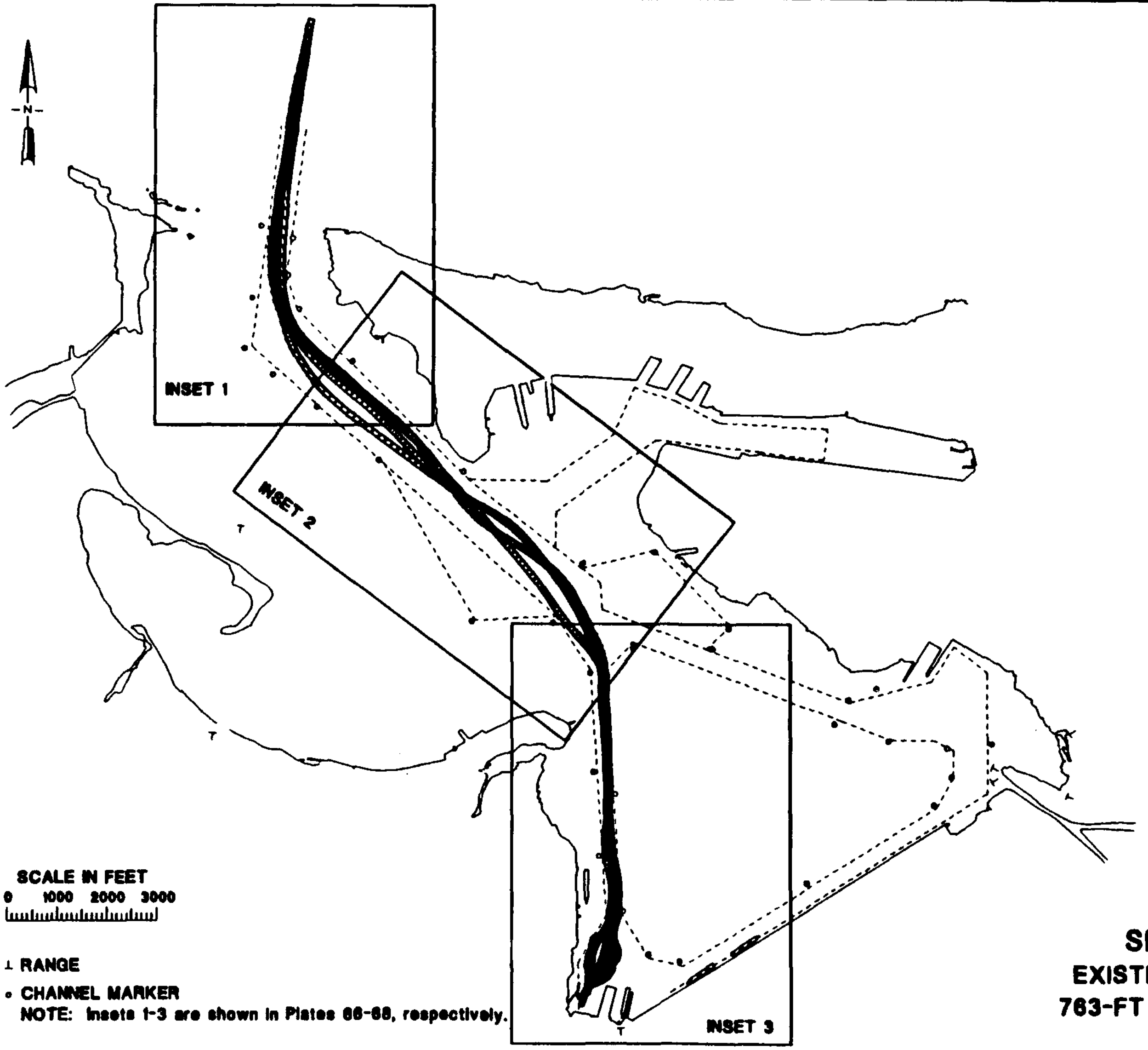
PARAMETER PLOT, WEEK 1
AVERAGE MINIMUM CLEARANCE
OUTBOUND CONTAINER SHIP



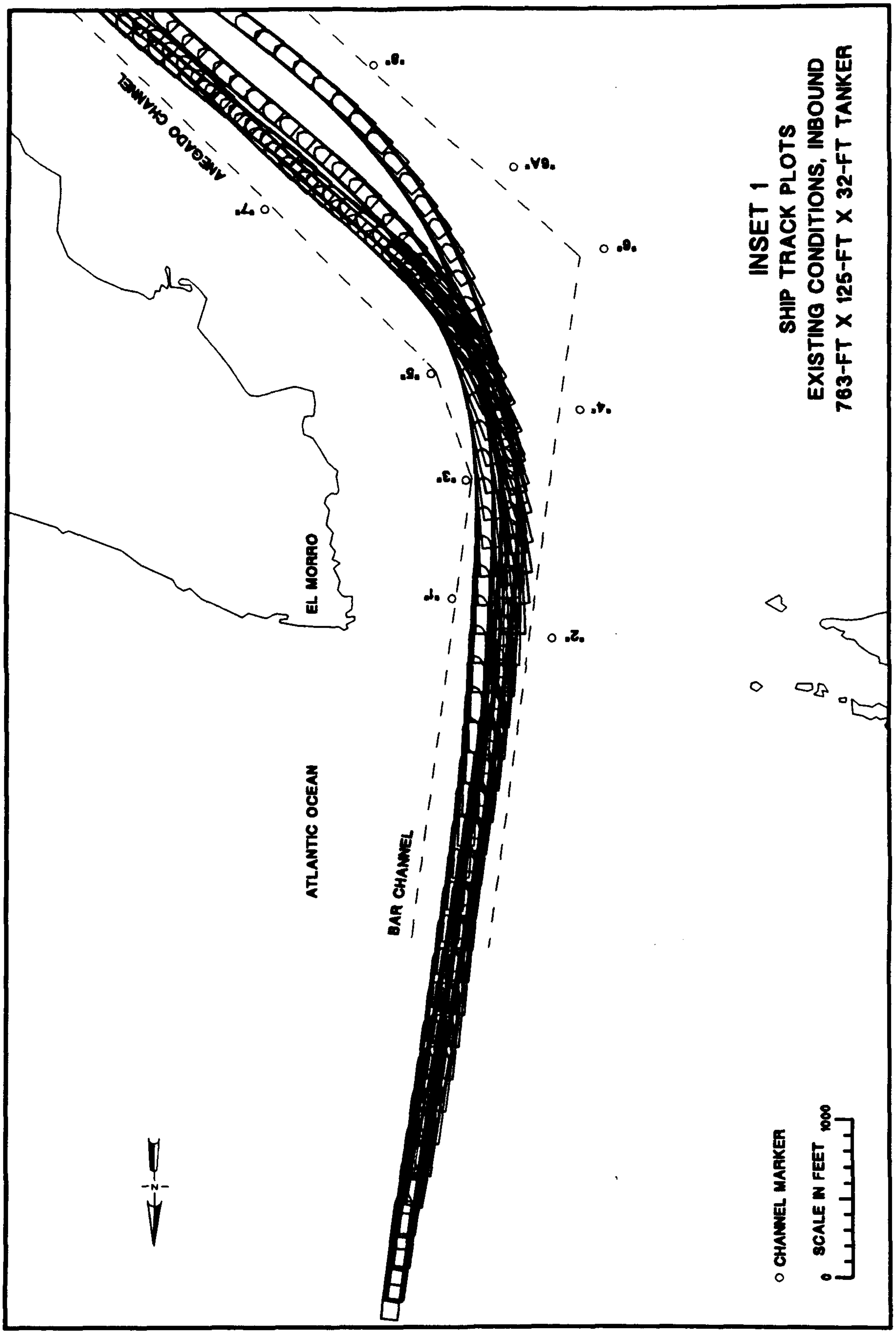
PARAMETER PLOT, WEEK 1
AVERAGE RPM AND RUDDER
OUTBOUND CONTAINER SHIP

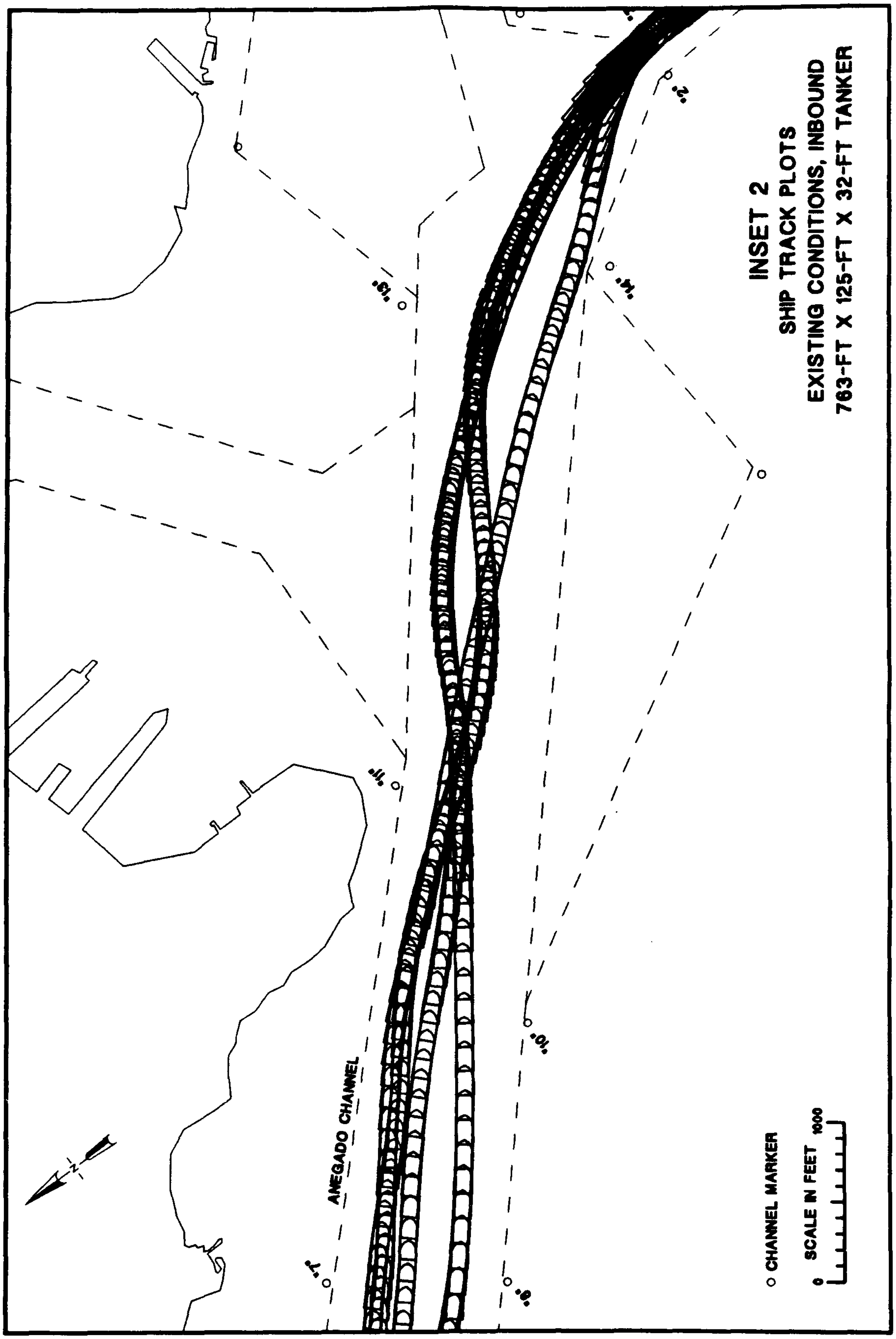


PARAMETER PLOT, WEEK 1
AVERAGE SPEED AND DRIFT ANGLE
OUTBOUND CONTAINER SHIP



SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER


INSET 1
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
ANEGADO CHANNEL
BAR CHANNEL
ATLANTIC OCEAN
EL MORRO
"1"
"2"
"3"
"4"
"5"
"6"
"6A"
"7"
"8"
N
CHANNEL MARKER
SCALE IN FEET
0
1000



INSET 2
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER

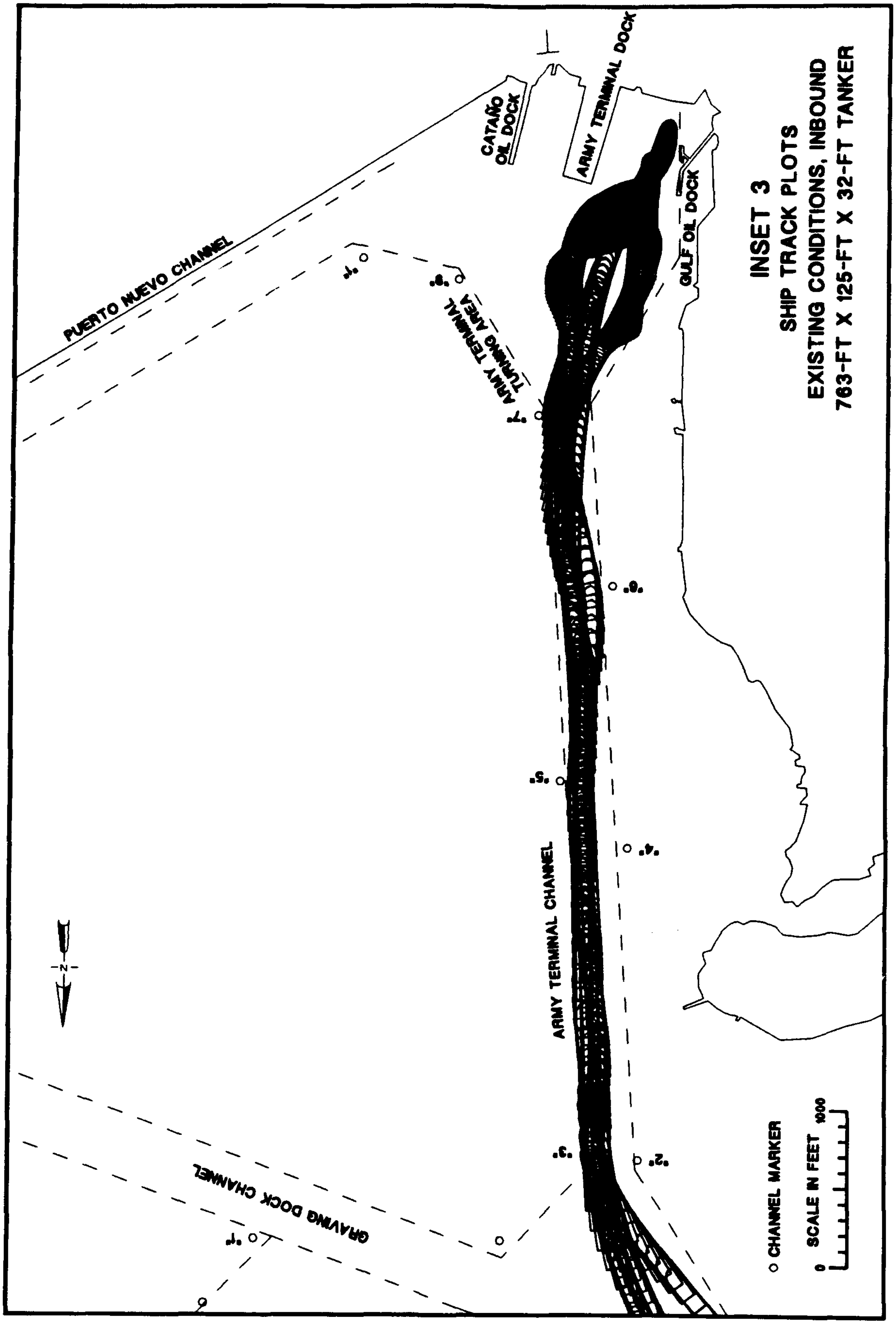
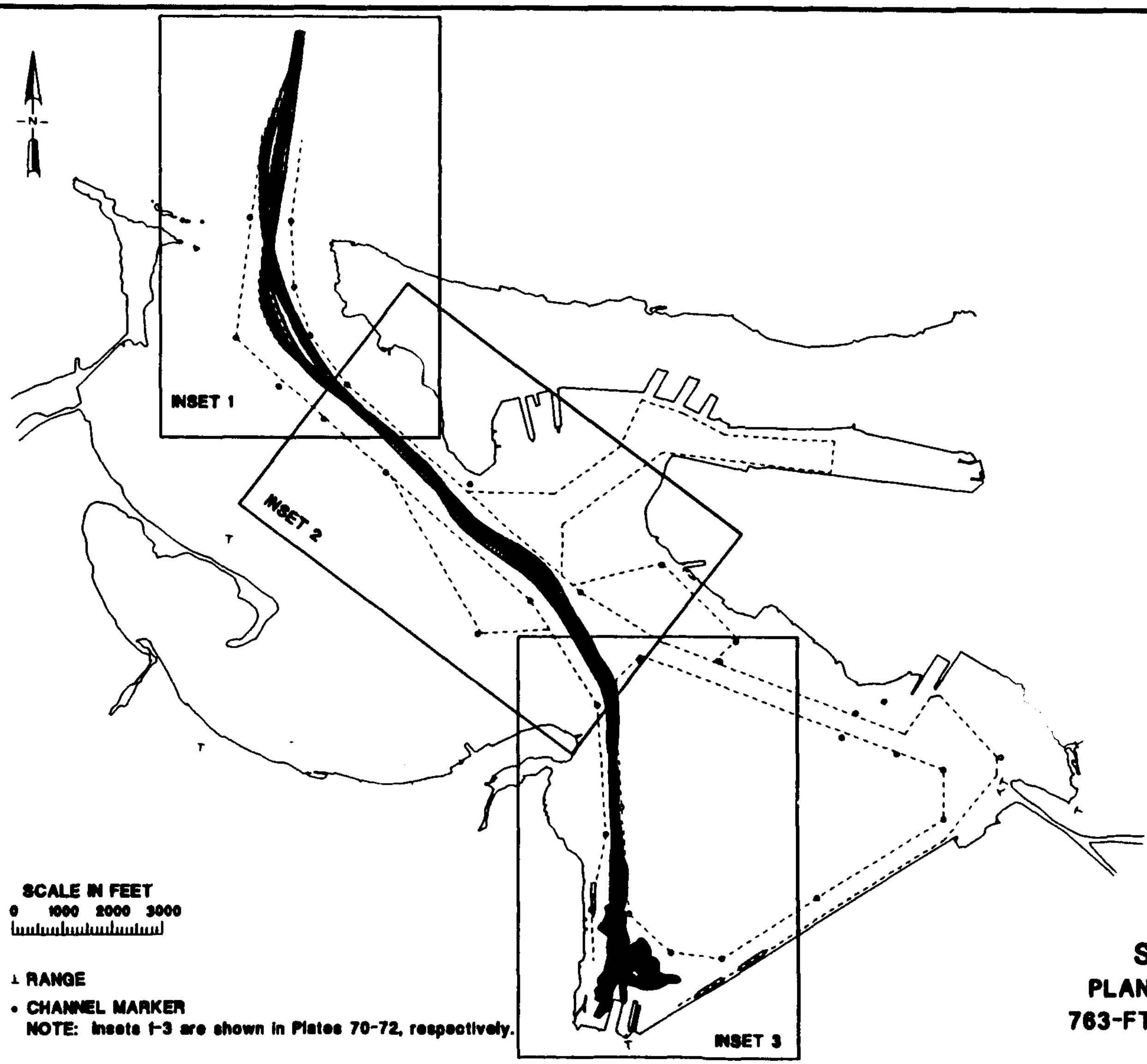
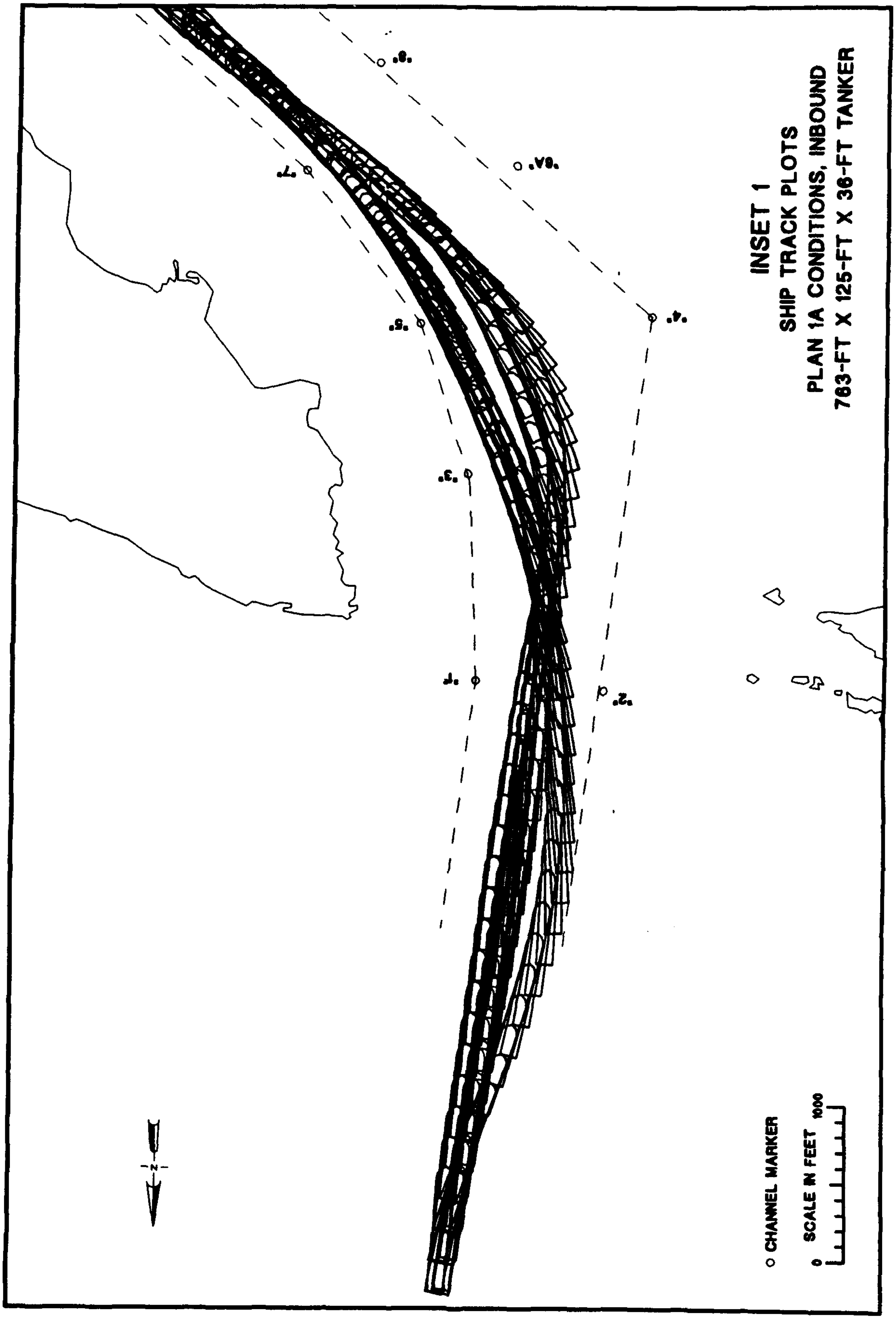
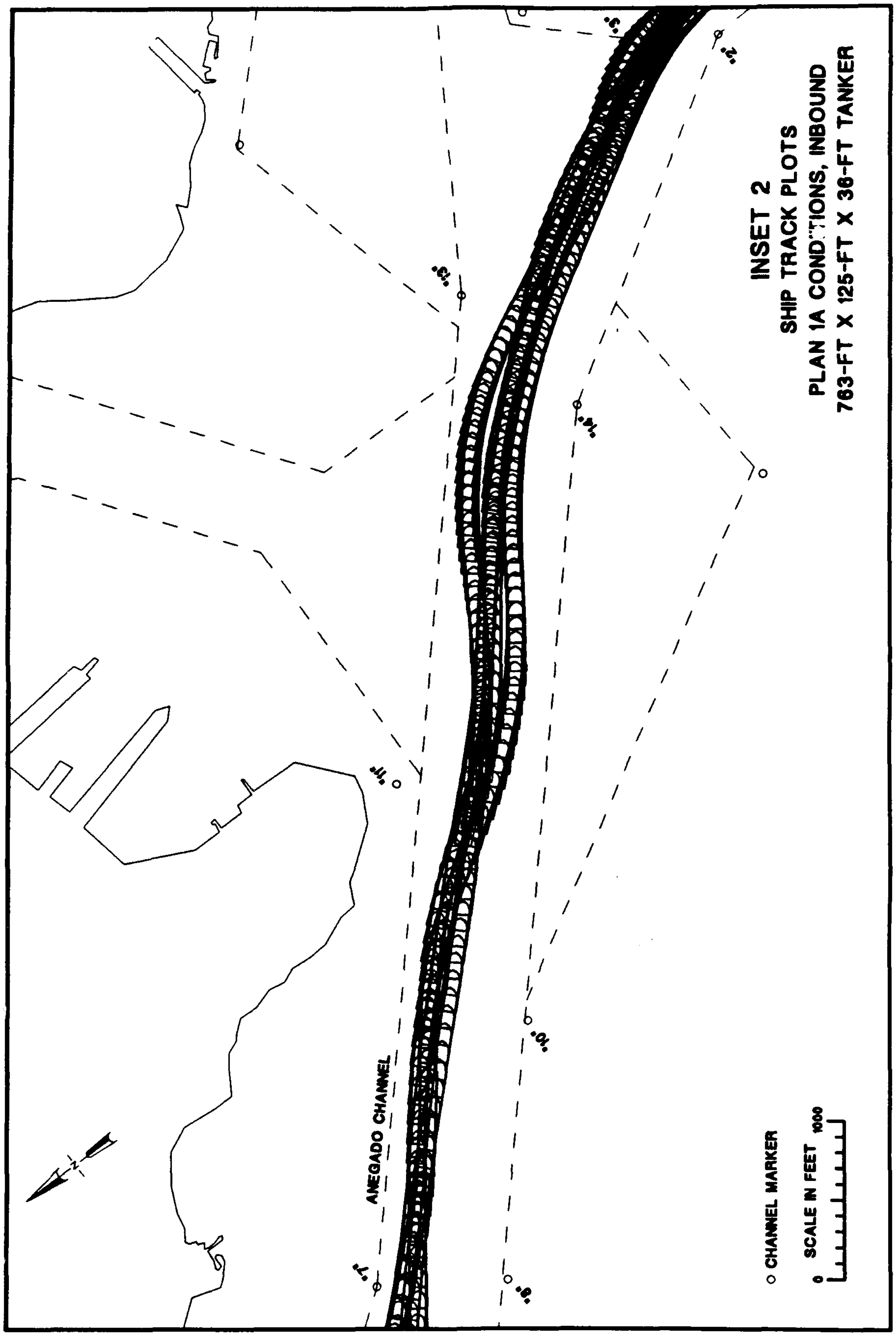

INSET 3
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
763-FT X 125-FT X 32-FT TANKER
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
"1"
"8"
"7"
"6"
"5"
"4"
"3"
"2"
"1"
N
CHANNEL MARKER
SCALE IN FEET
0
1000

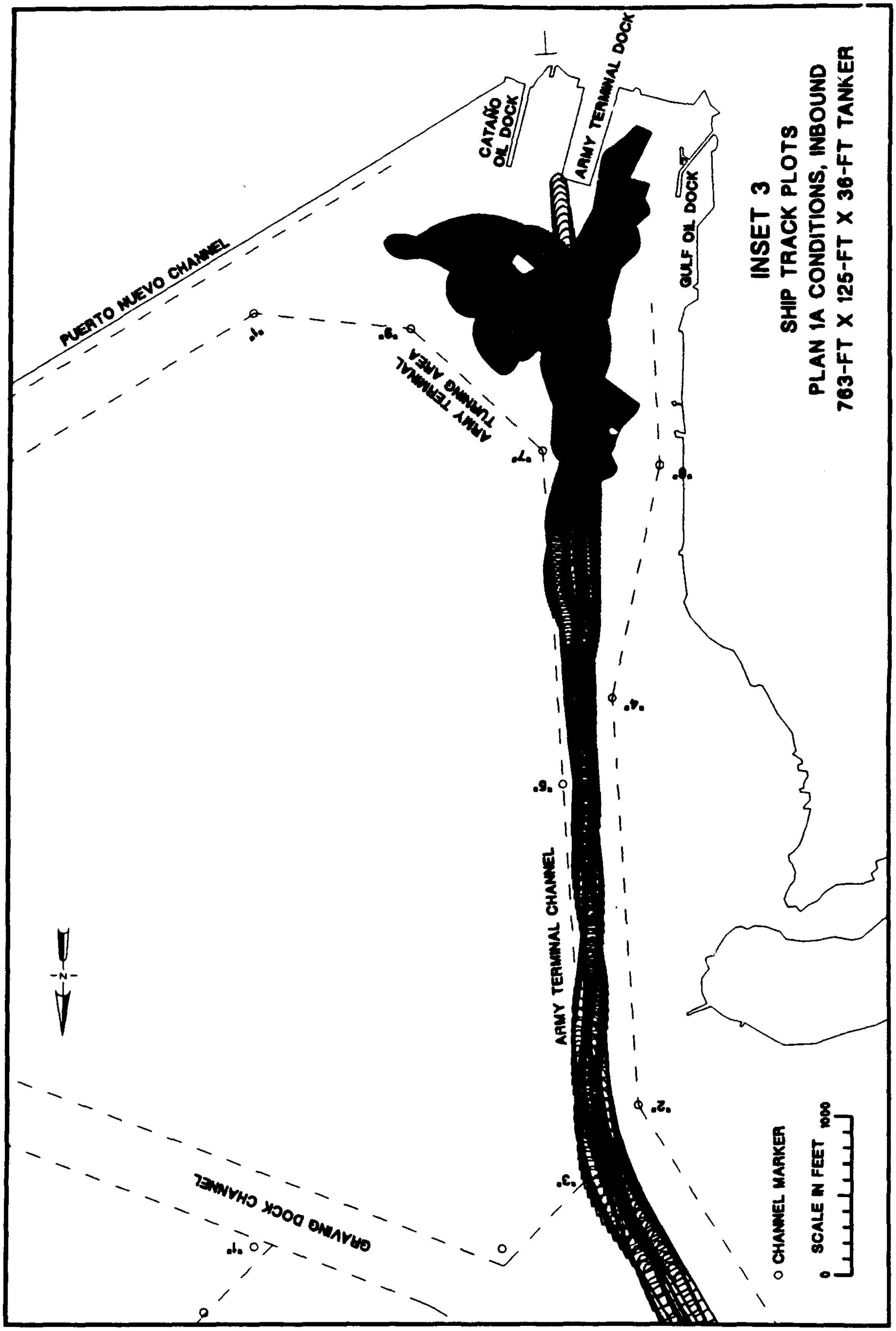
Plate 68



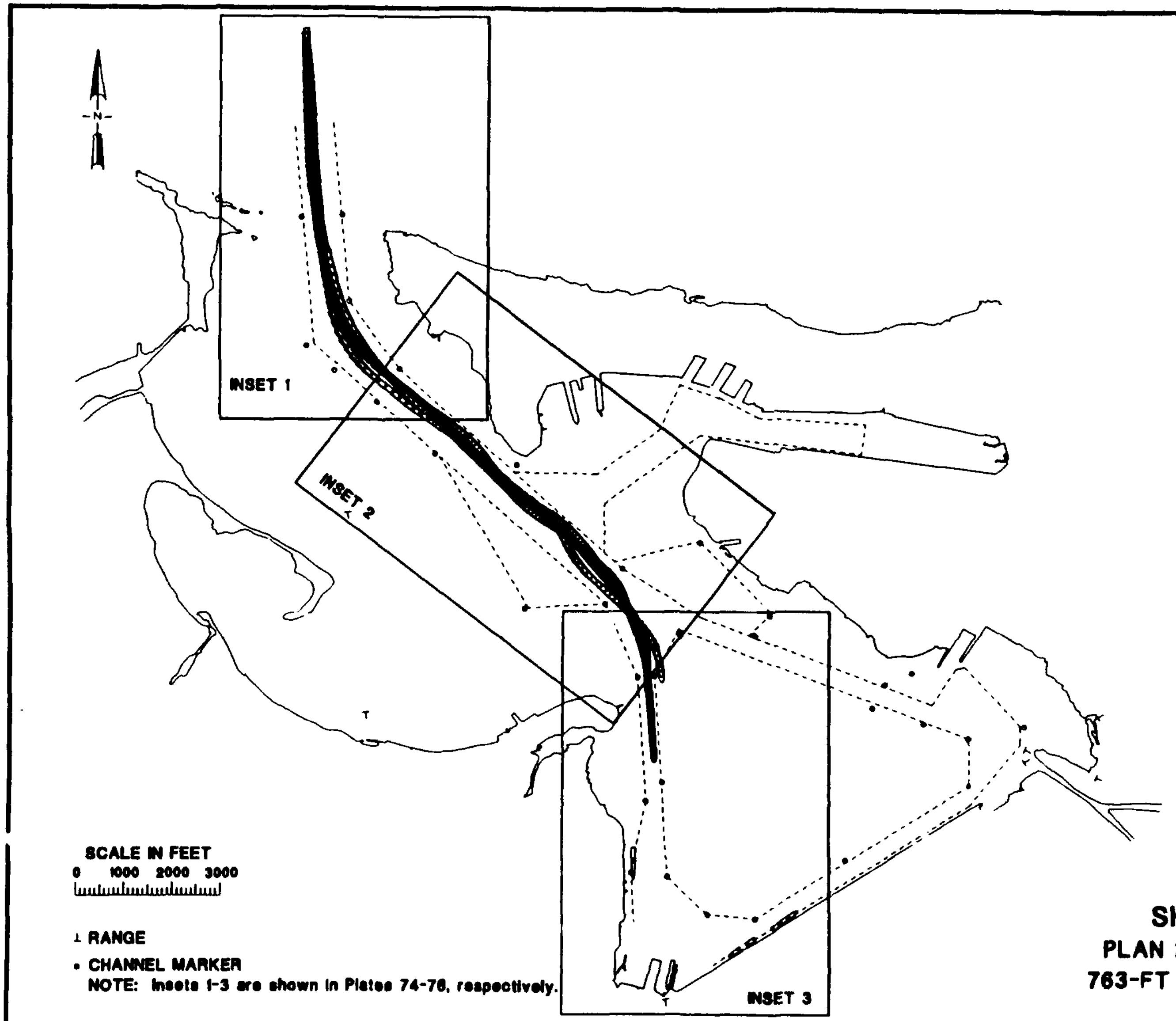
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
763-FT X 125-FT X 38-FT TANKER


INSET 1
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
○ CHANNEL MARKER
SCALE IN FEET
0
1000
N
"1"
"2"
"3"
"4"
"5"
"7"
"8"
"8A"


INSET 2
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
ANEGADO CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N



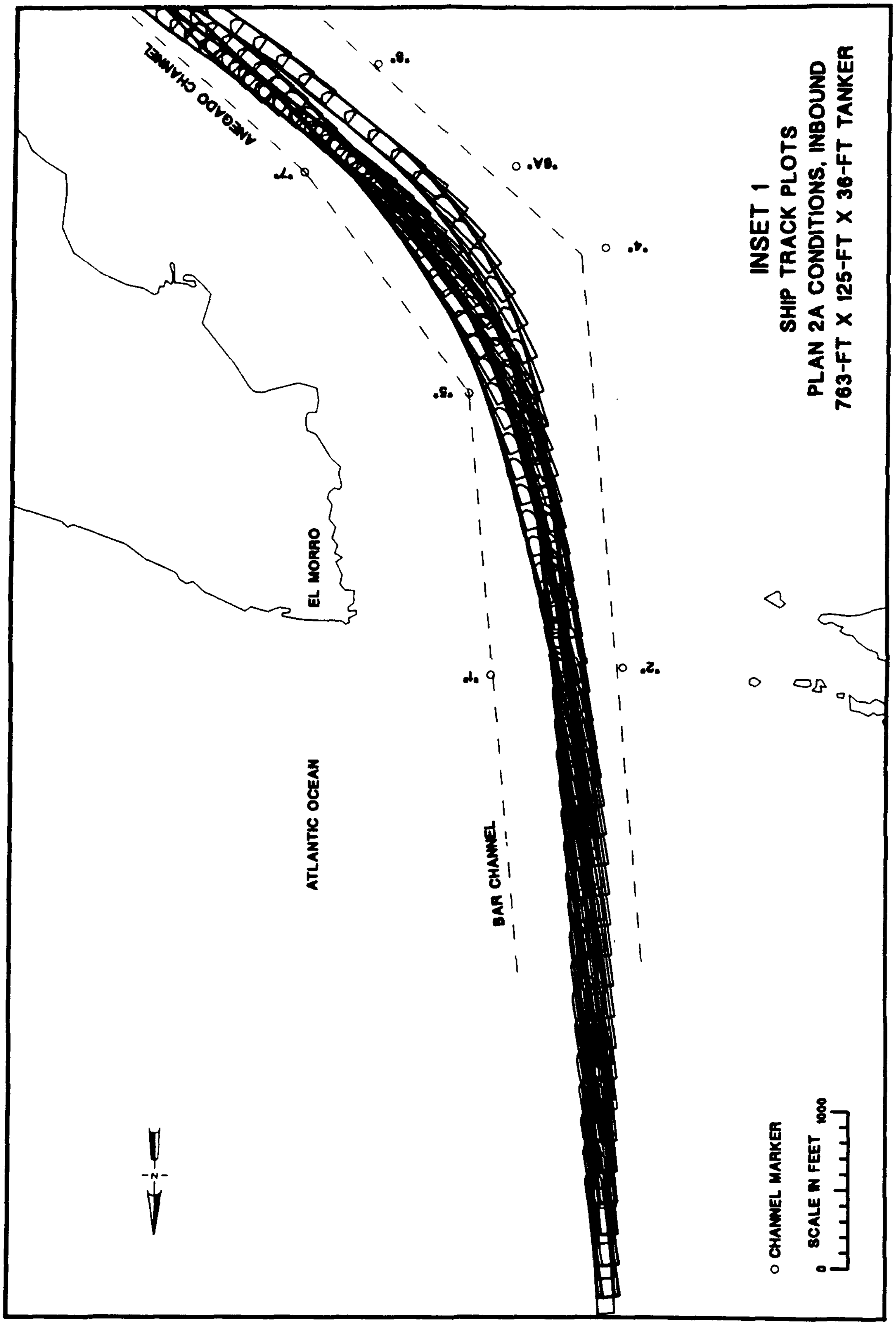
INSET 3
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER

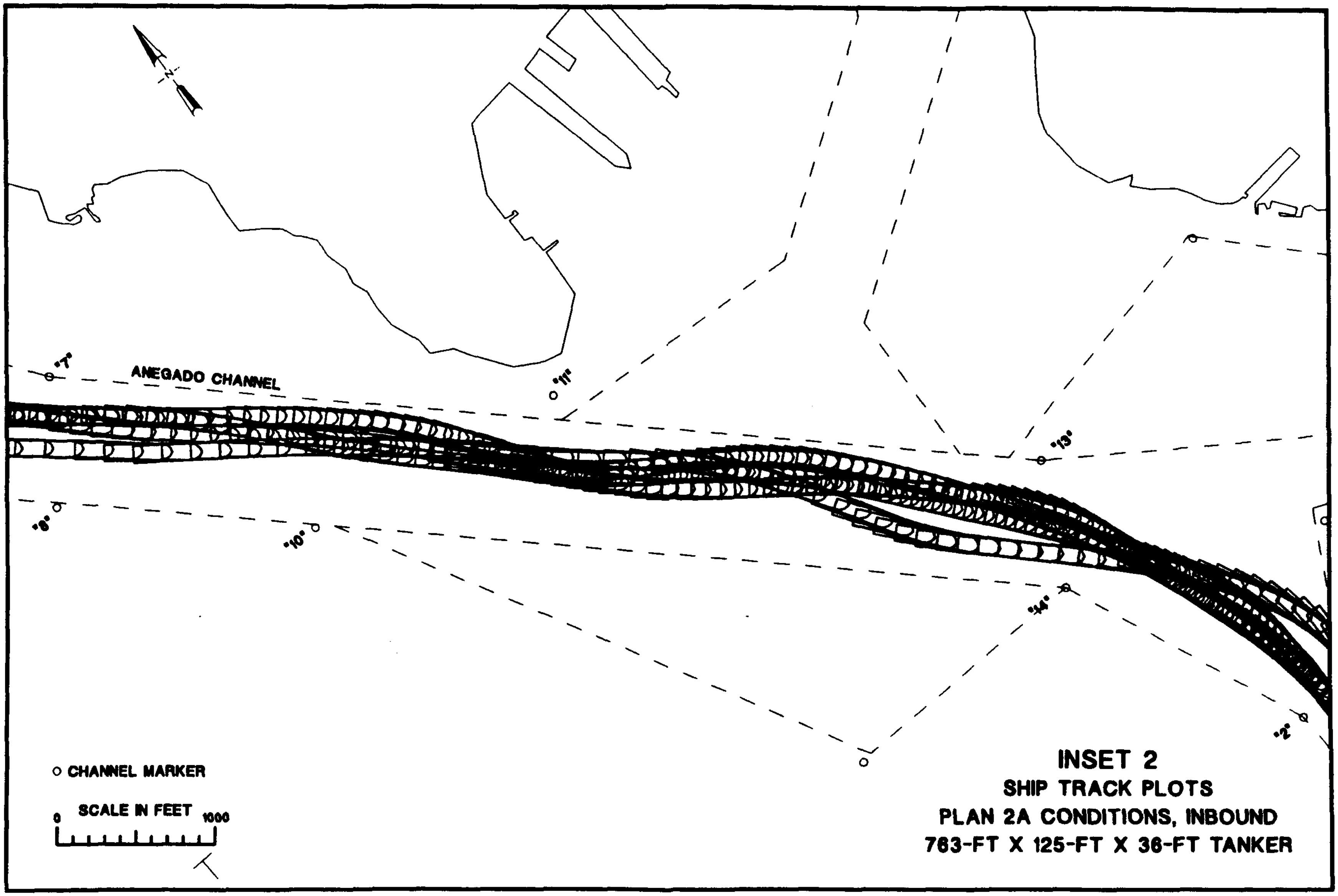


SHIP TRACK PLOTS

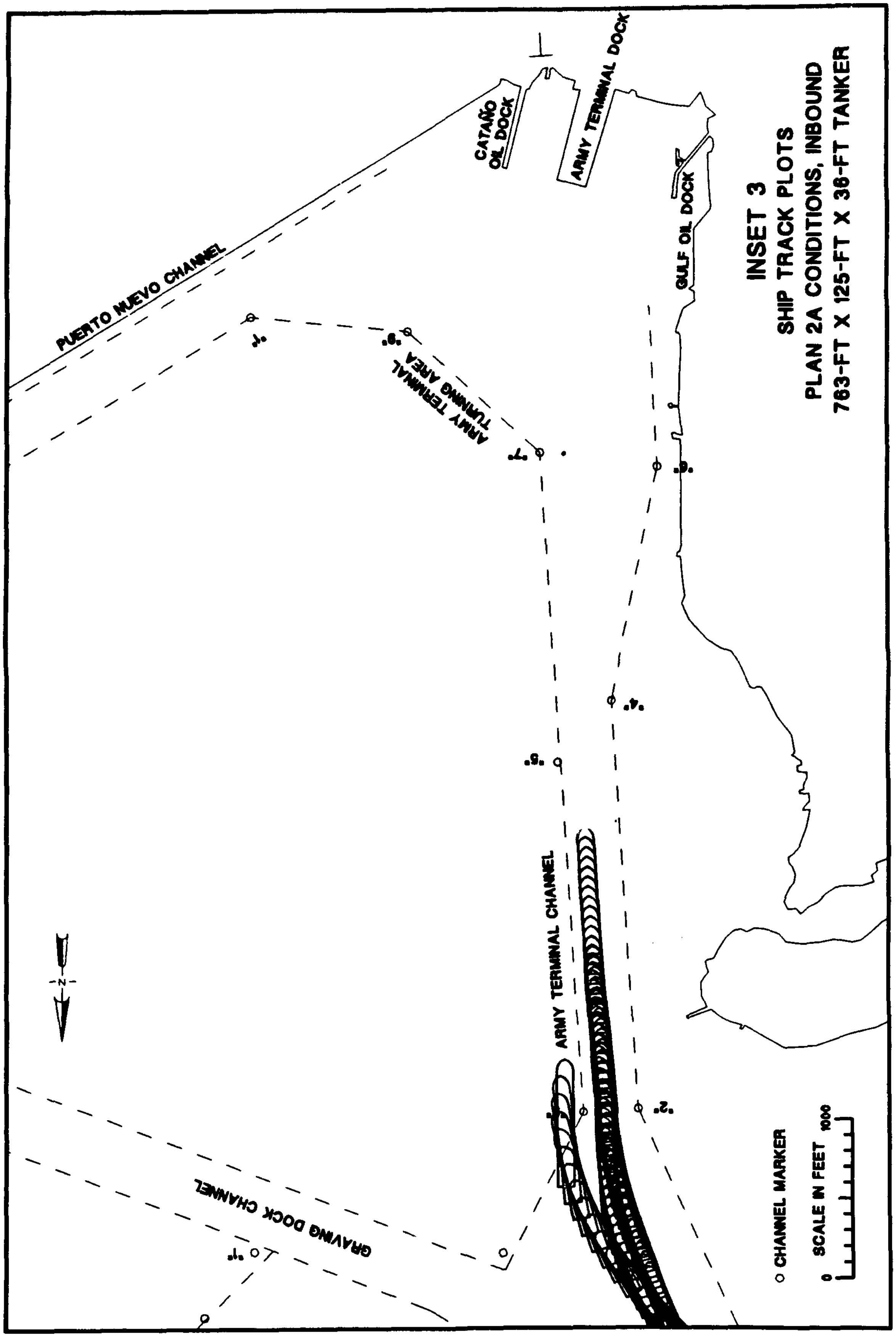
PLAN 2A CONDITIONS, INBOUND

763-FT X 125-FT X 36-FT TANKER


INSET 1
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
1
2
3
4
6A
7
8
N
CHANNEL MARKER
SCALE IN FEET
0
1000

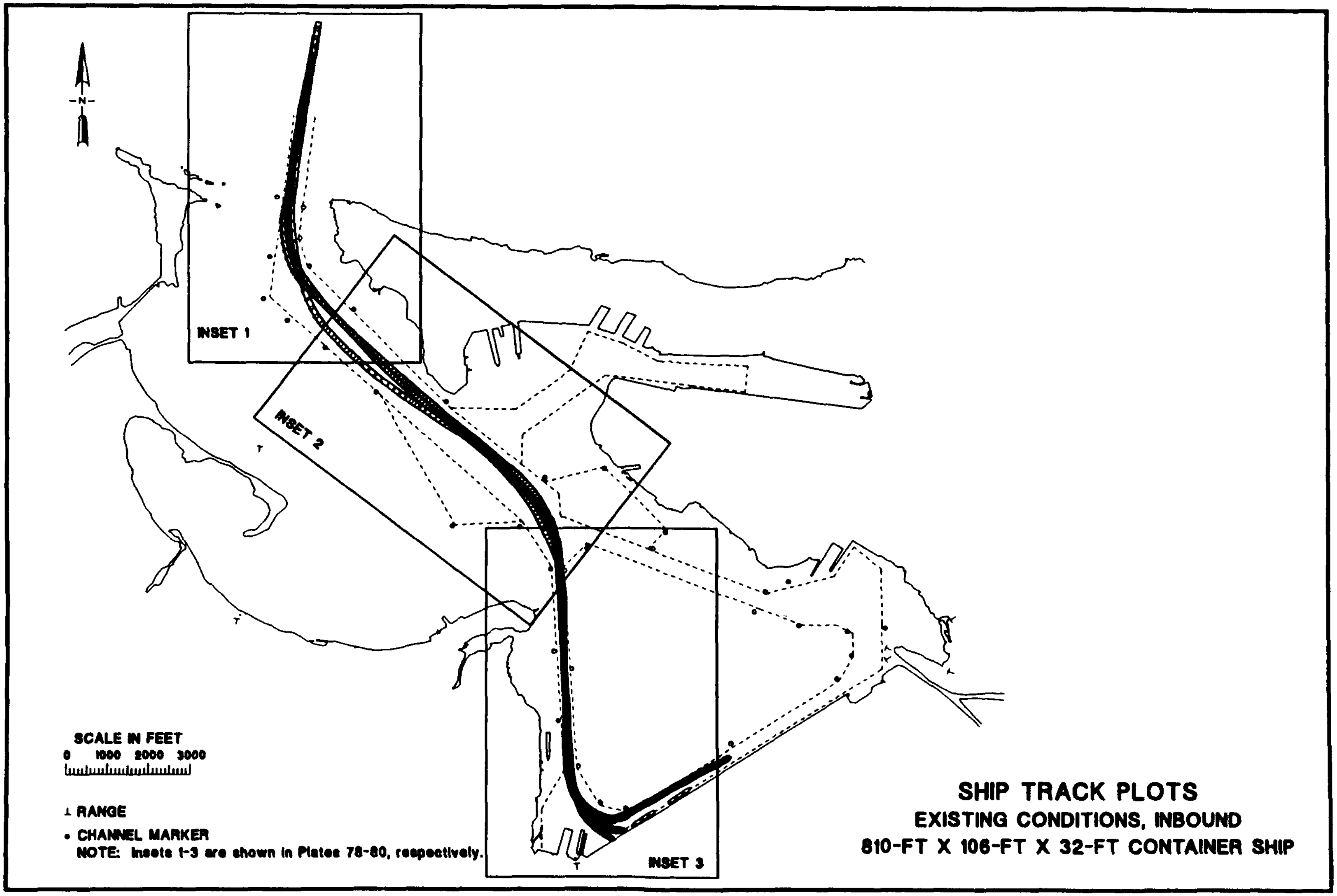


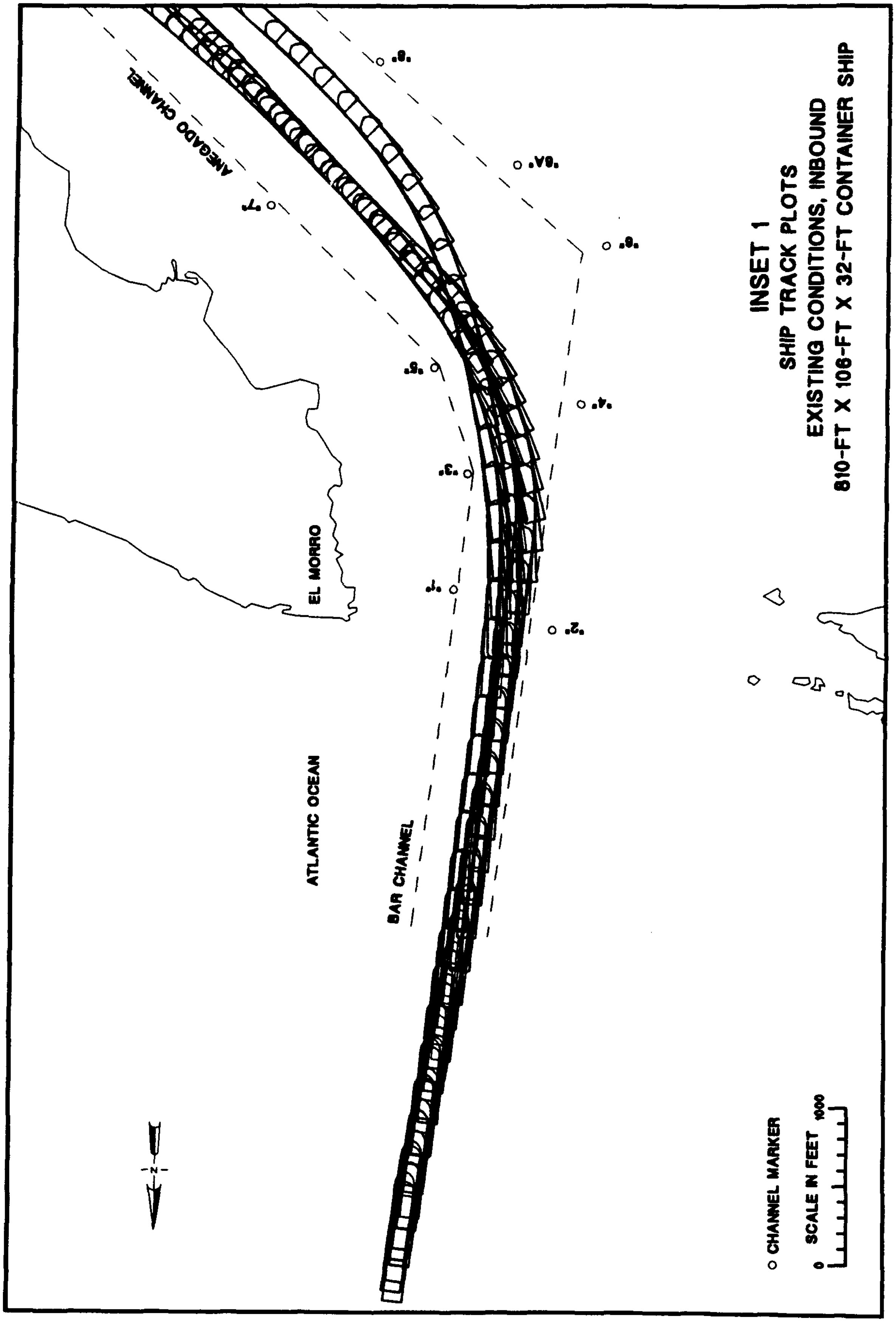
INSET 2
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER

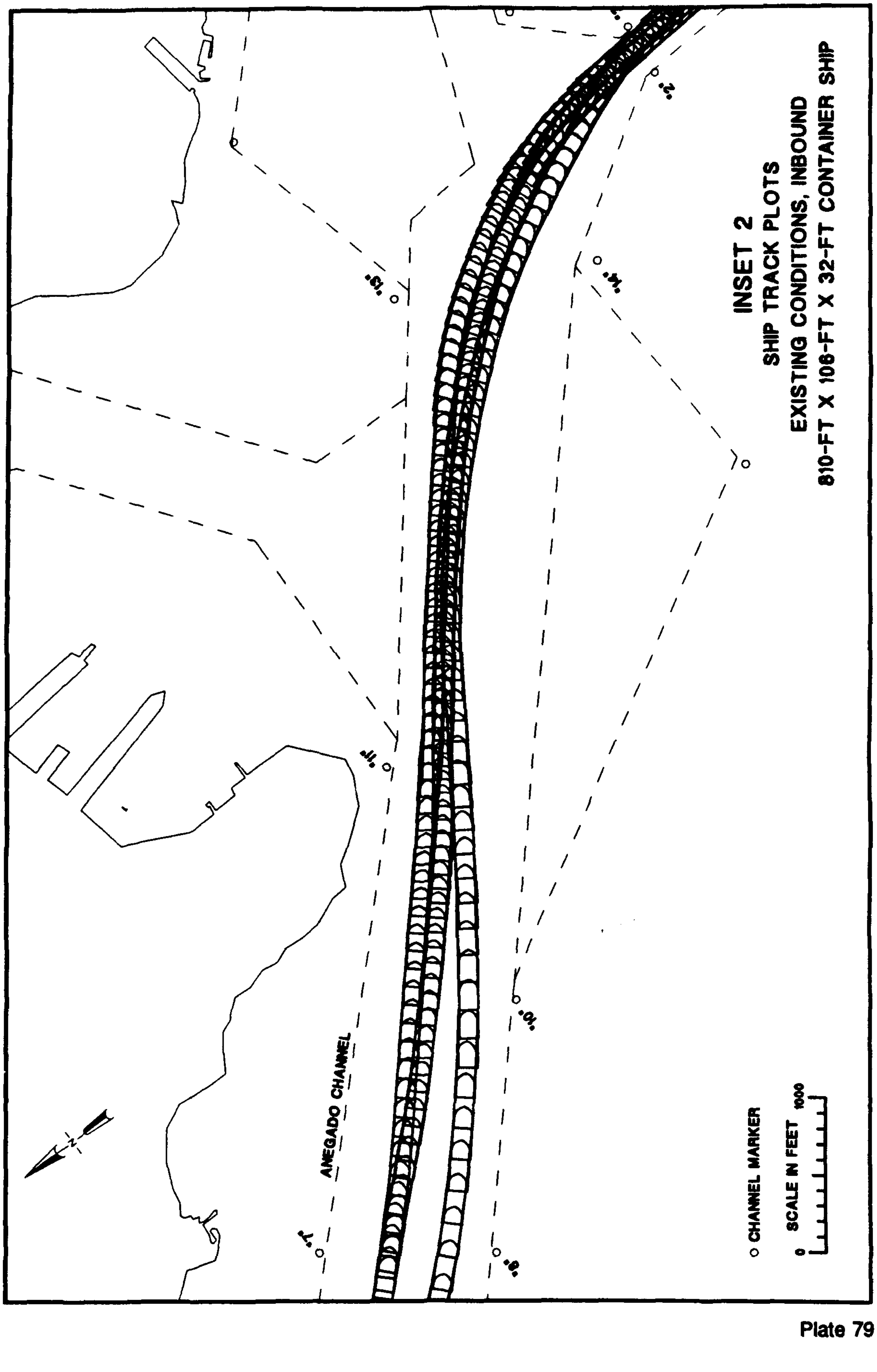


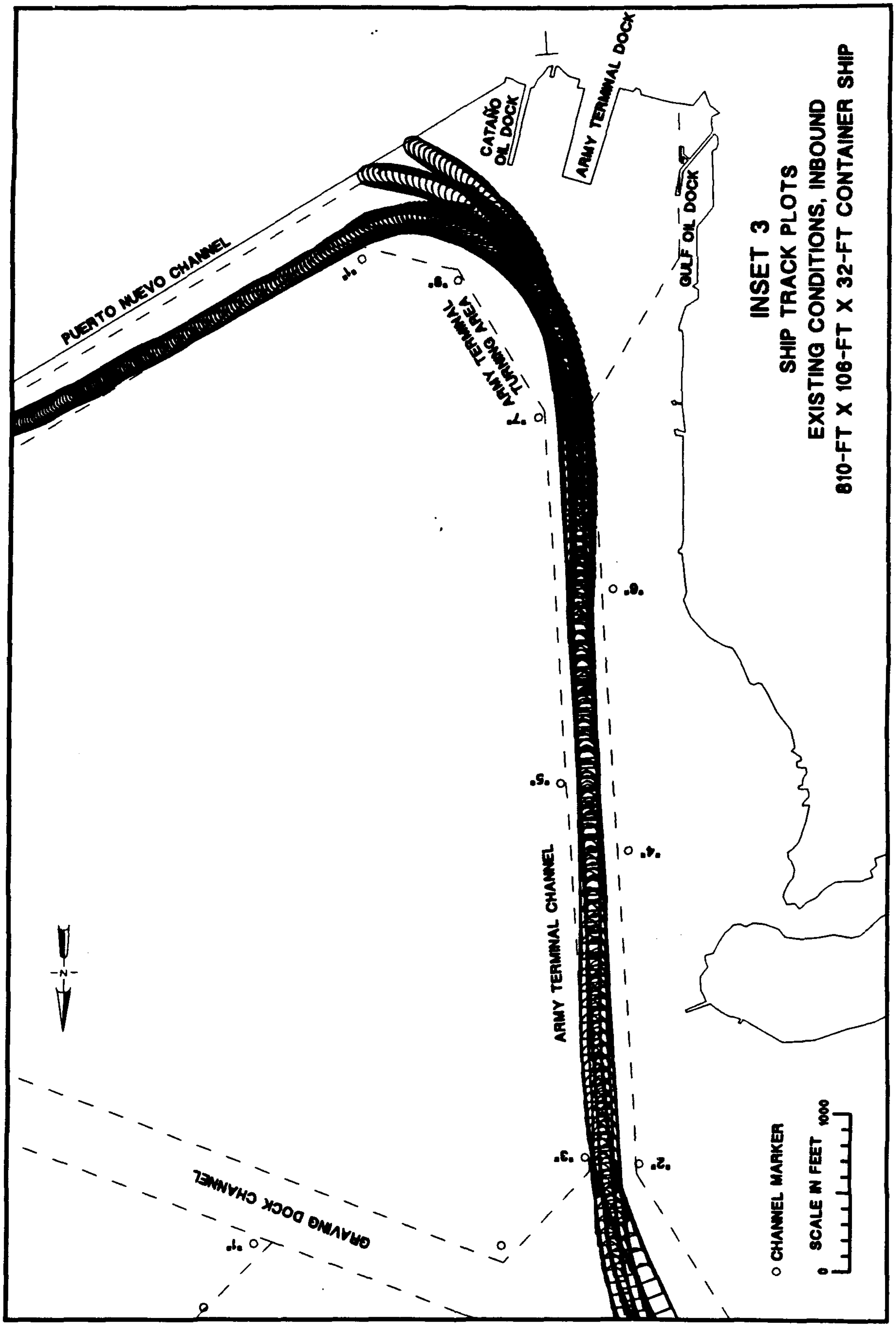
INSET 3
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
763-FT X 125-FT X 36-FT TANKER
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
PUERTO NUEVO CHANNEL
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

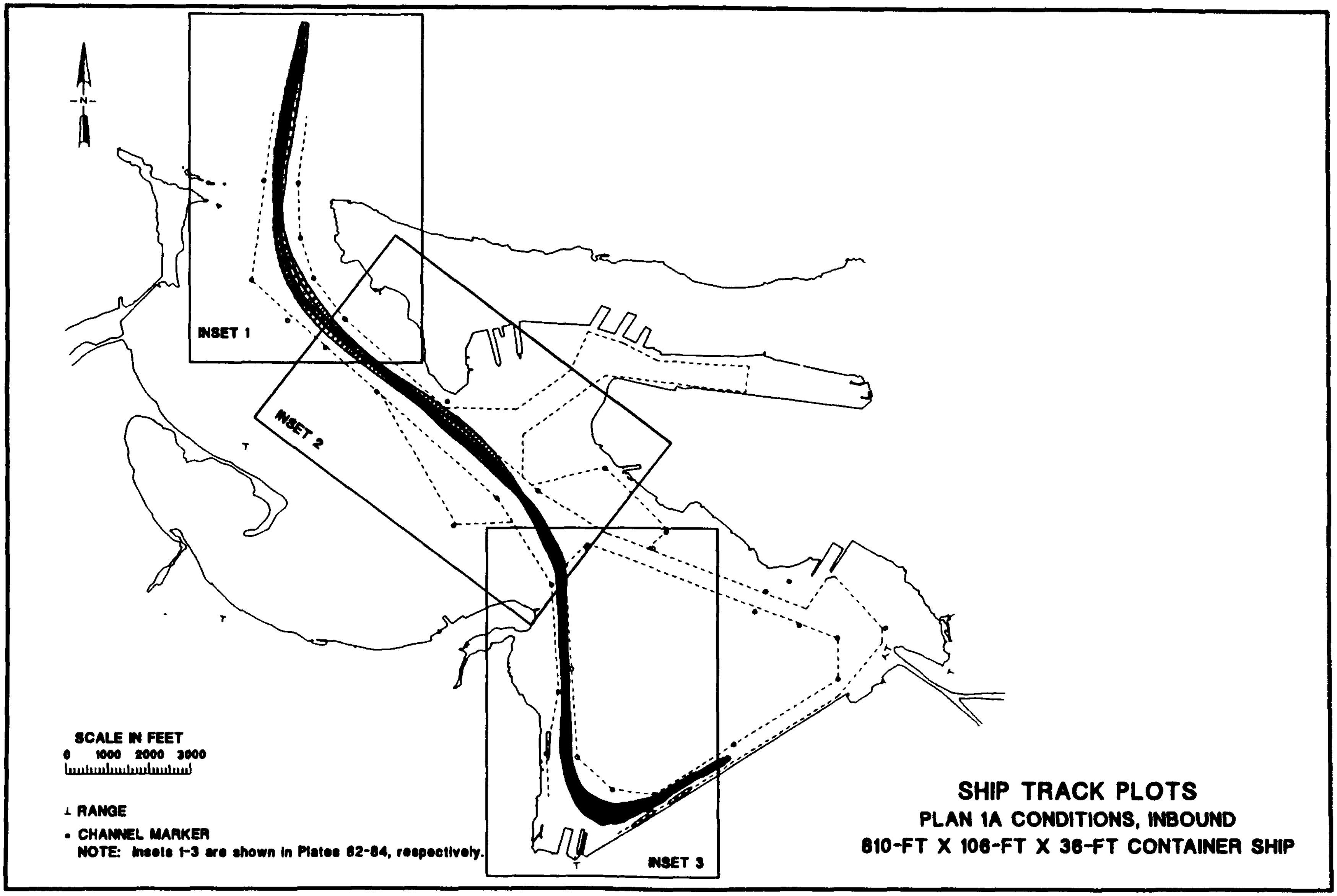
Plate 76

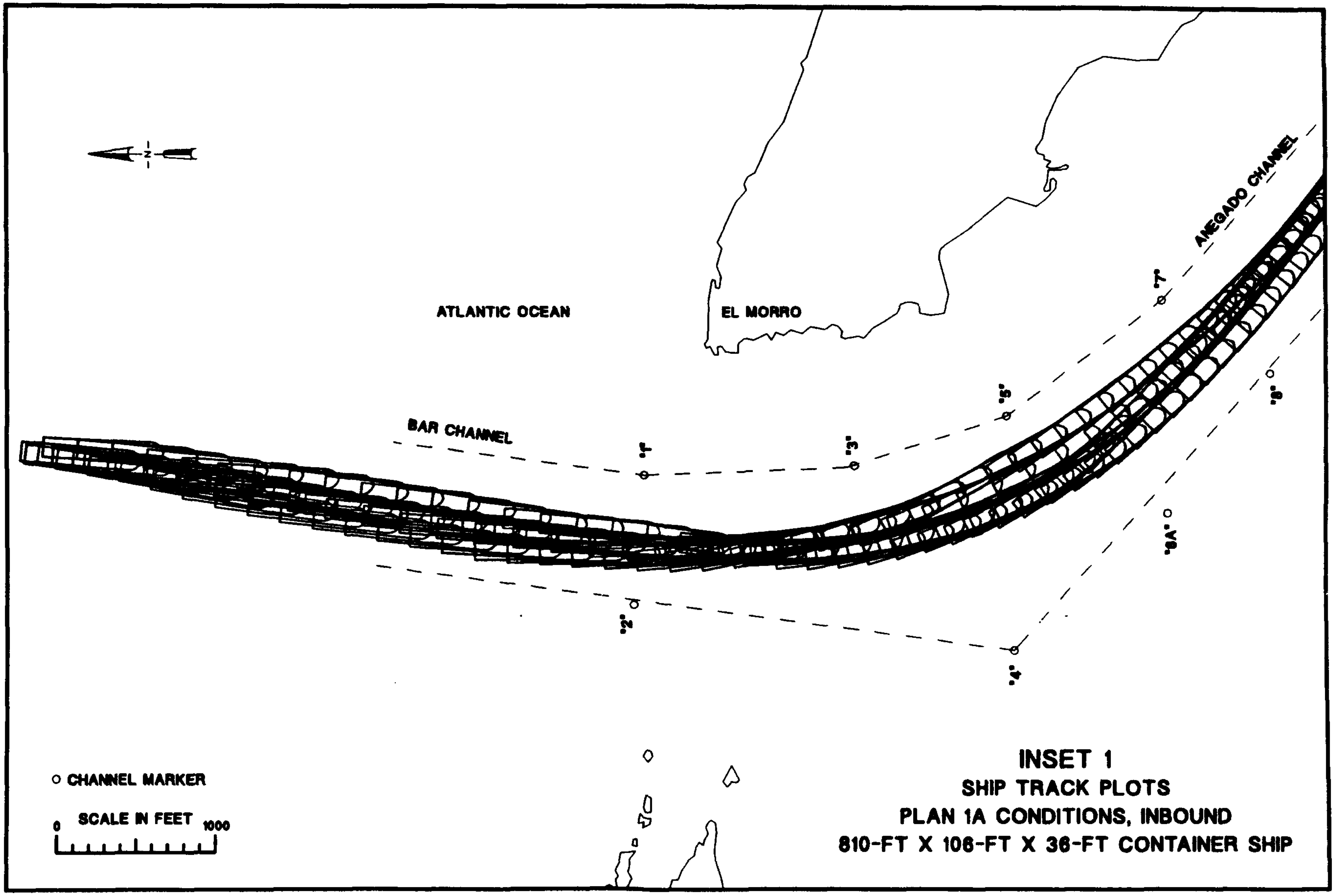

N
INSET 1
INSET 2
INSET 3
SCALE IN FEET
0 1000 2000 3000
⊥ RANGE
• CHANNEL MARKER
NOTE: Insets 1-3 are shown in Plates 78-80, respectively.
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP


INSET 1
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N
1
2
3
4
5
6
6A
7
8

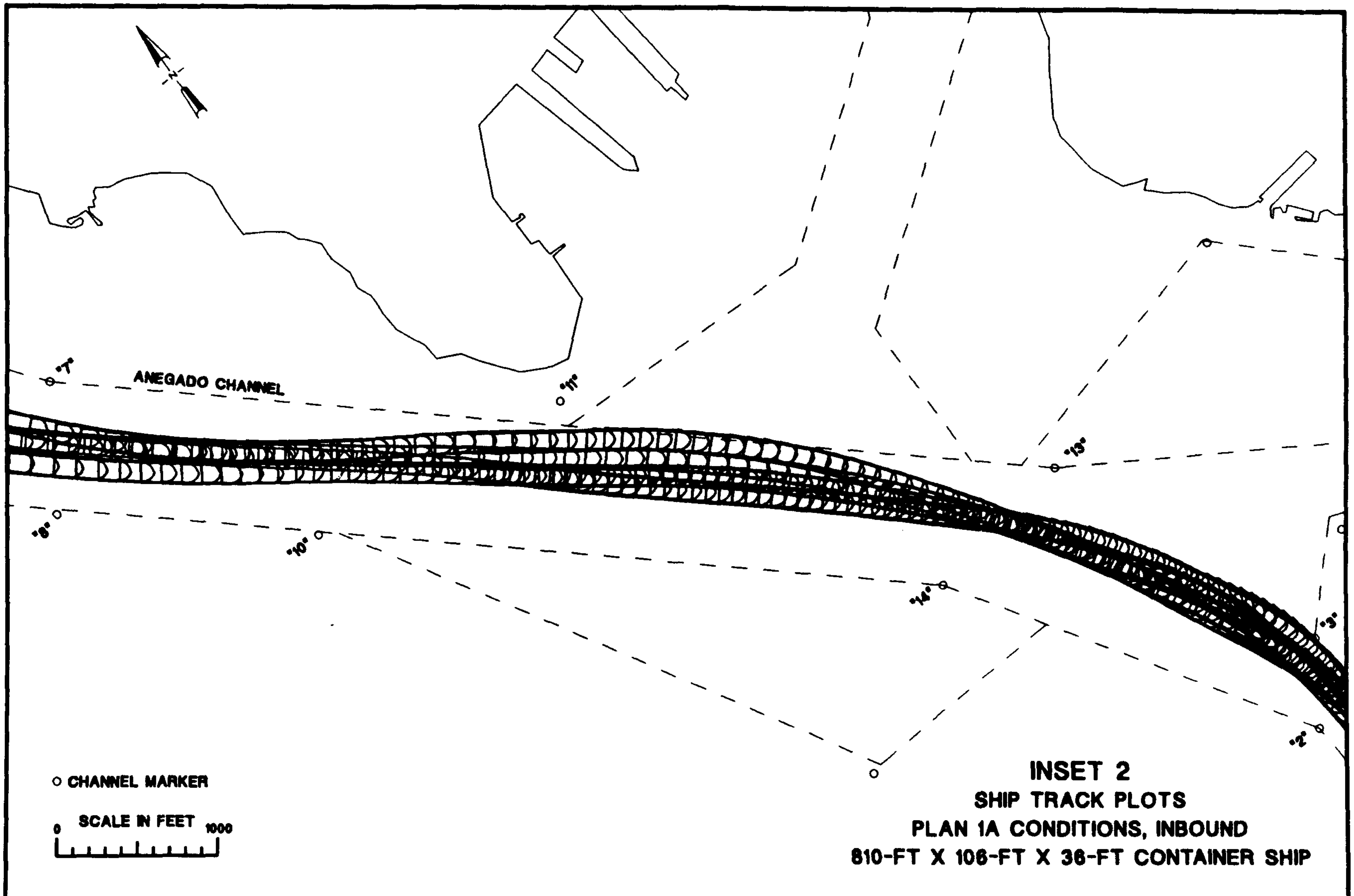

INSET 2
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
ANEGADO CHANNEL
N
○ CHANNEL MARKER
0 SCALE IN FEET 1000


INSET 3
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
"1"
"8"
"7"
"6"
"5"
"4"
"3"
"2"
"1"
N
CHANNEL MARKER
SCALE IN FEET
0
1000


N
INSET 1
INSET 2
INSET 3
SCALE IN FEET
0 1000 2000 3000
⊥ RANGE
• CHANNEL MARKER
NOTE: Insets 1-3 are shown in Plates 82-84, respectively.
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 1
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

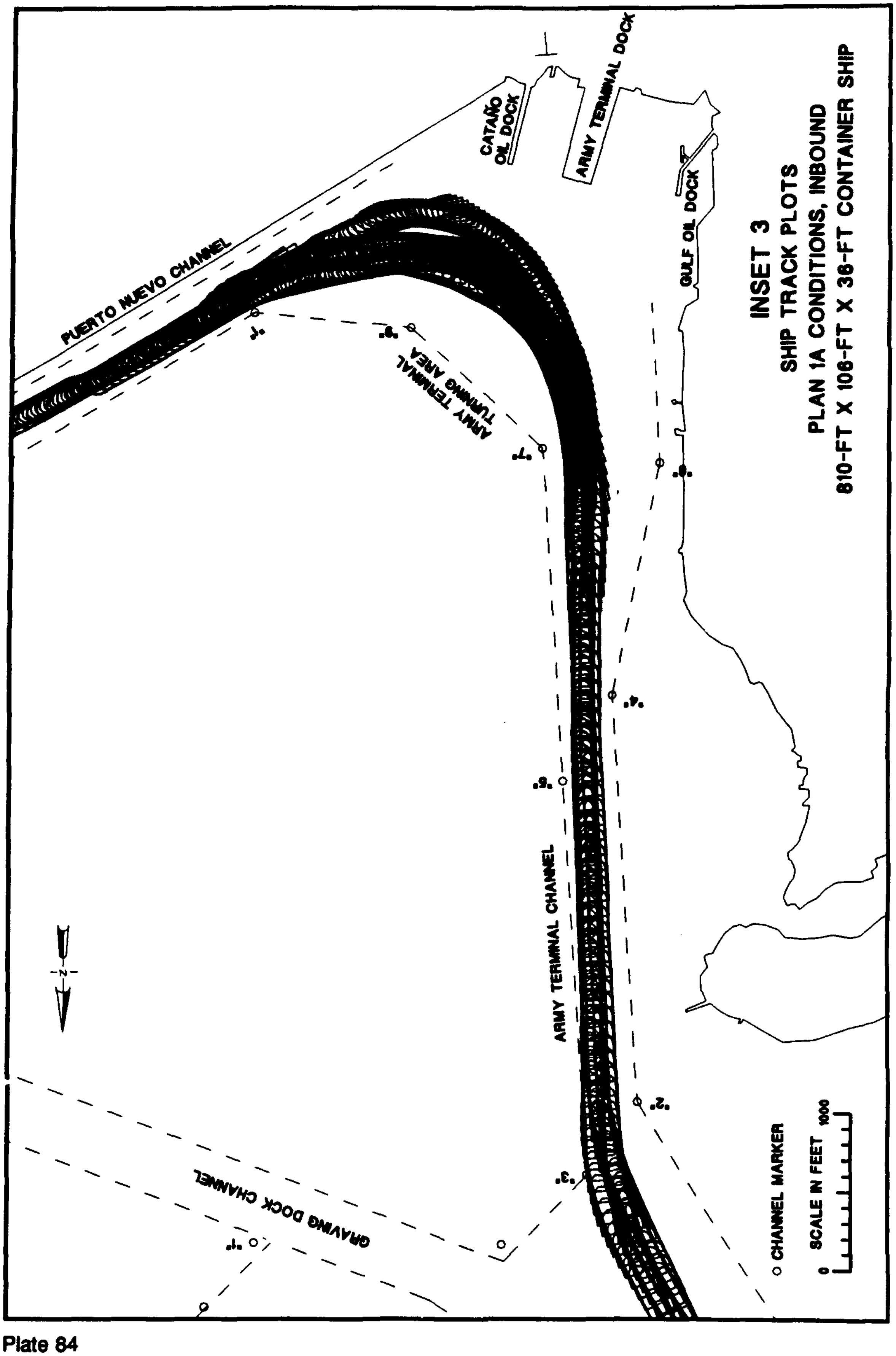


INSET 2

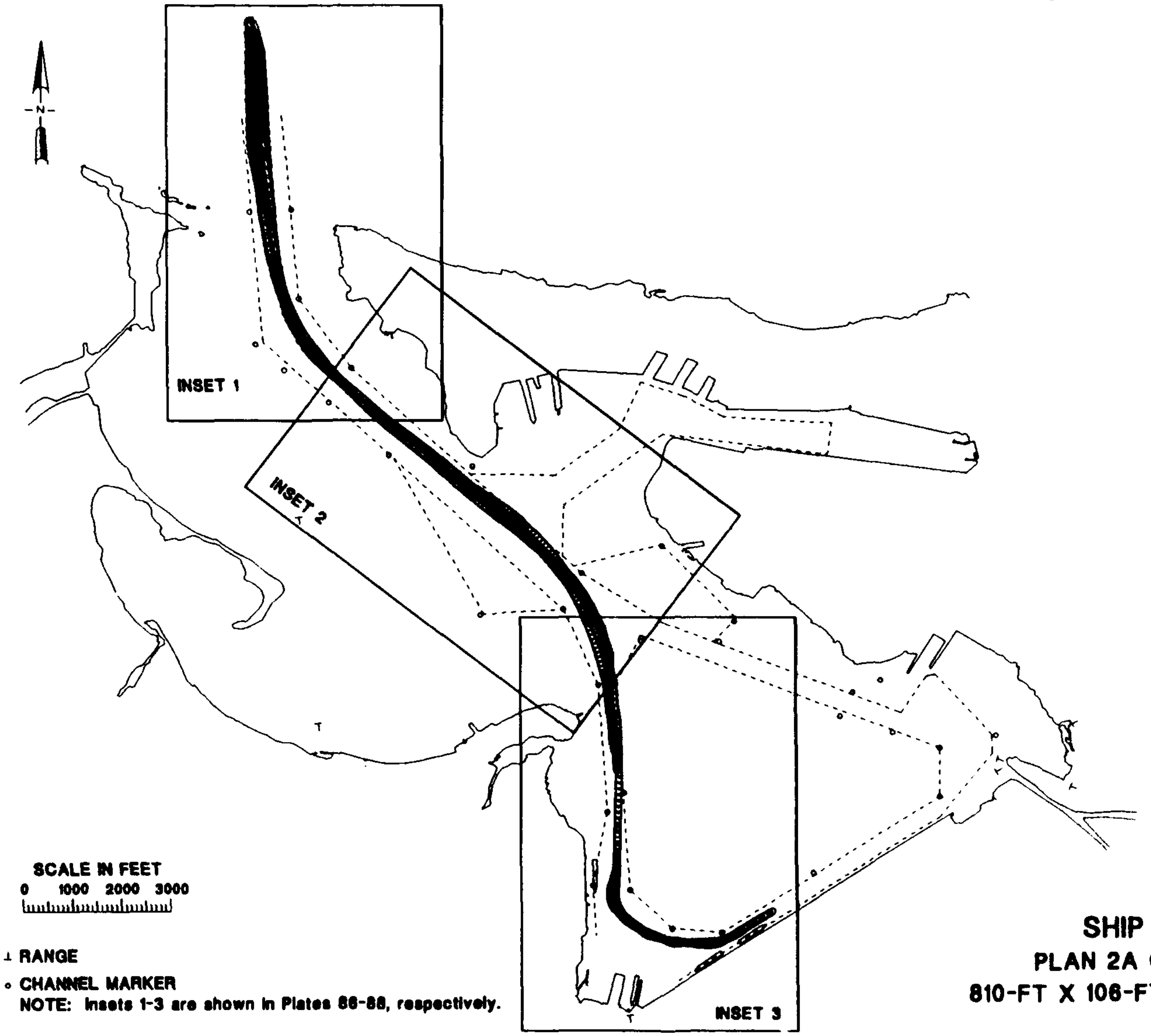
SHIP TRACK PLOTS

PLAN 1A CONDITIONS, INBOUND

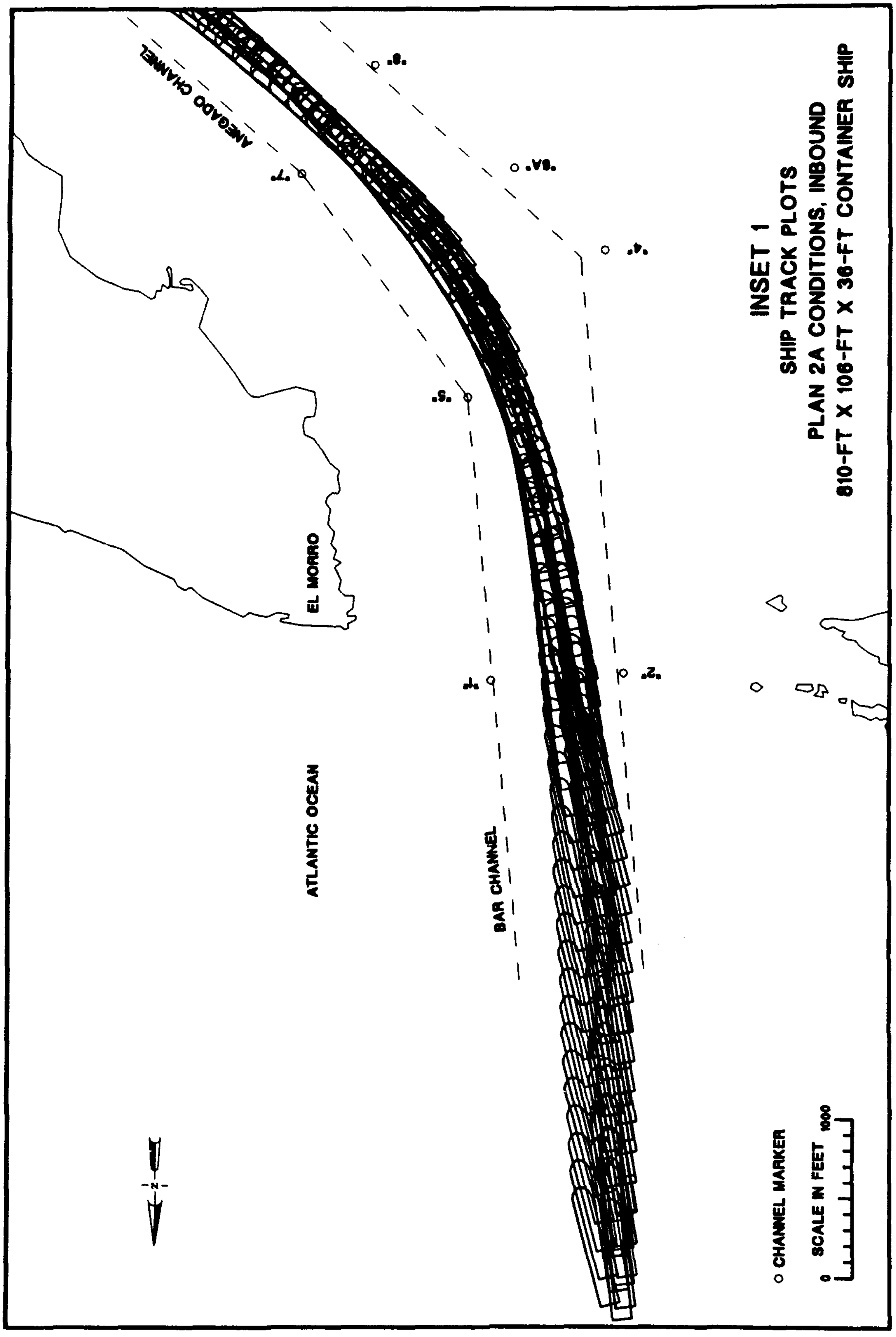
810-FT X 106-FT X 36-FT CONTAINER SHIP



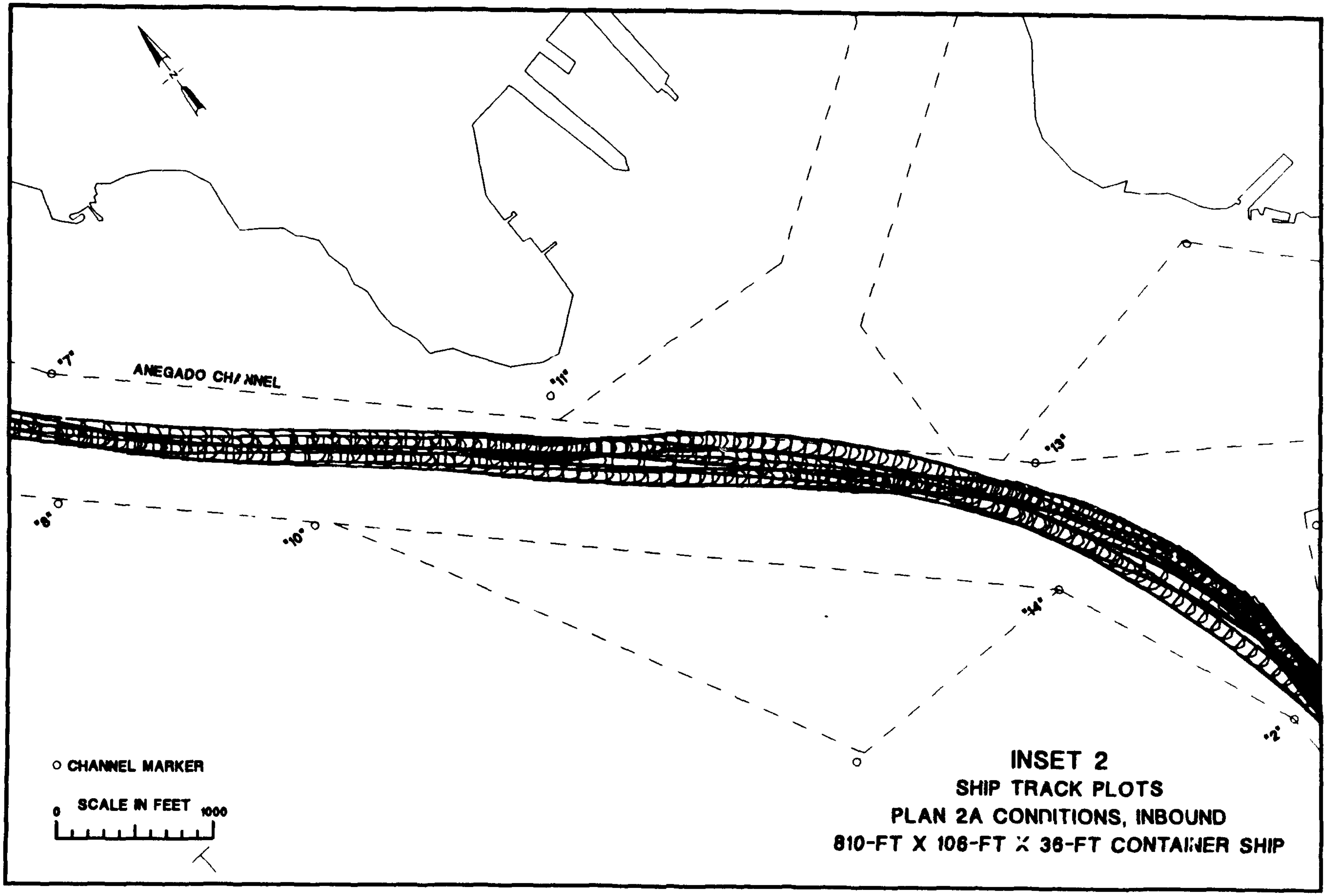
INSET 3
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



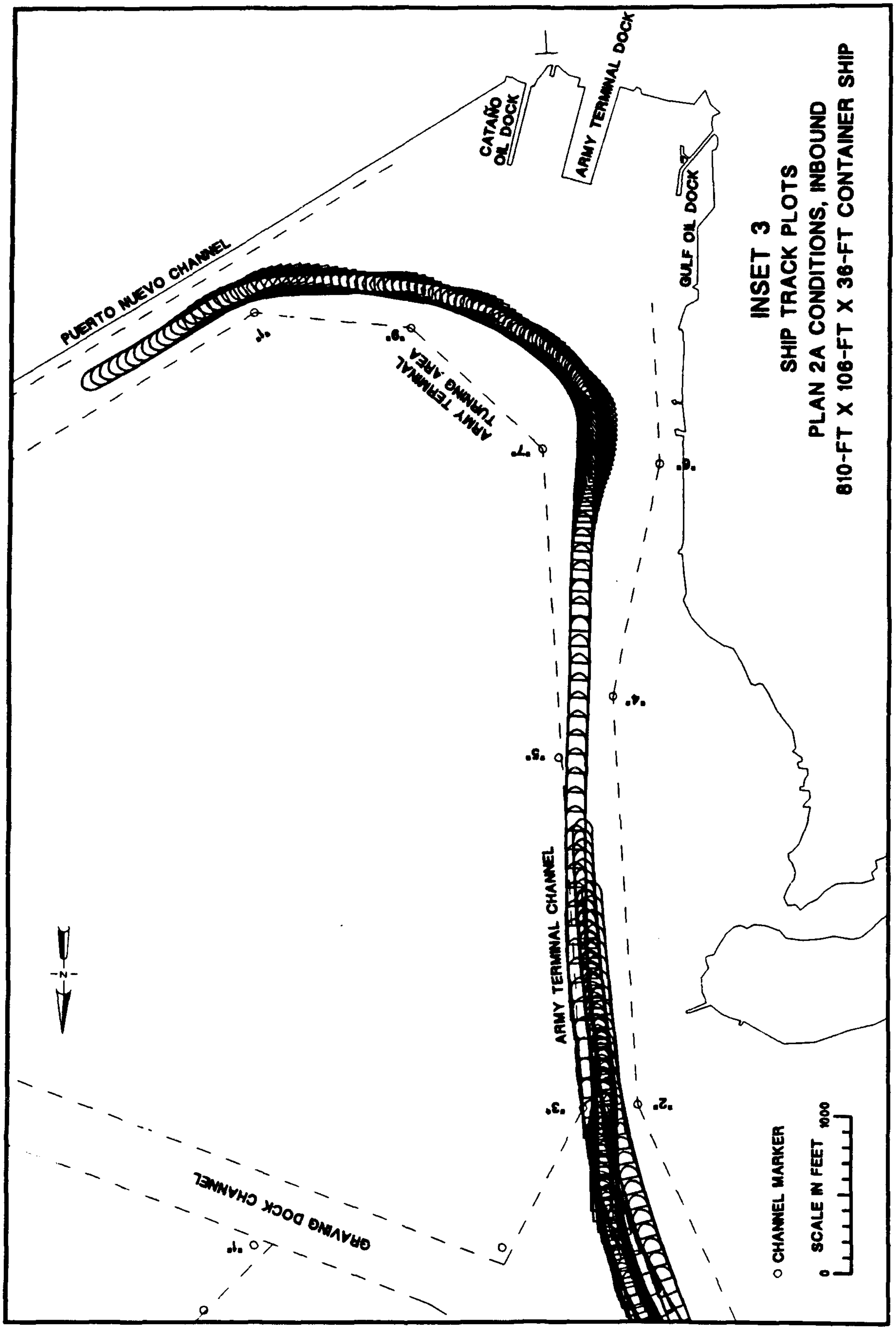
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

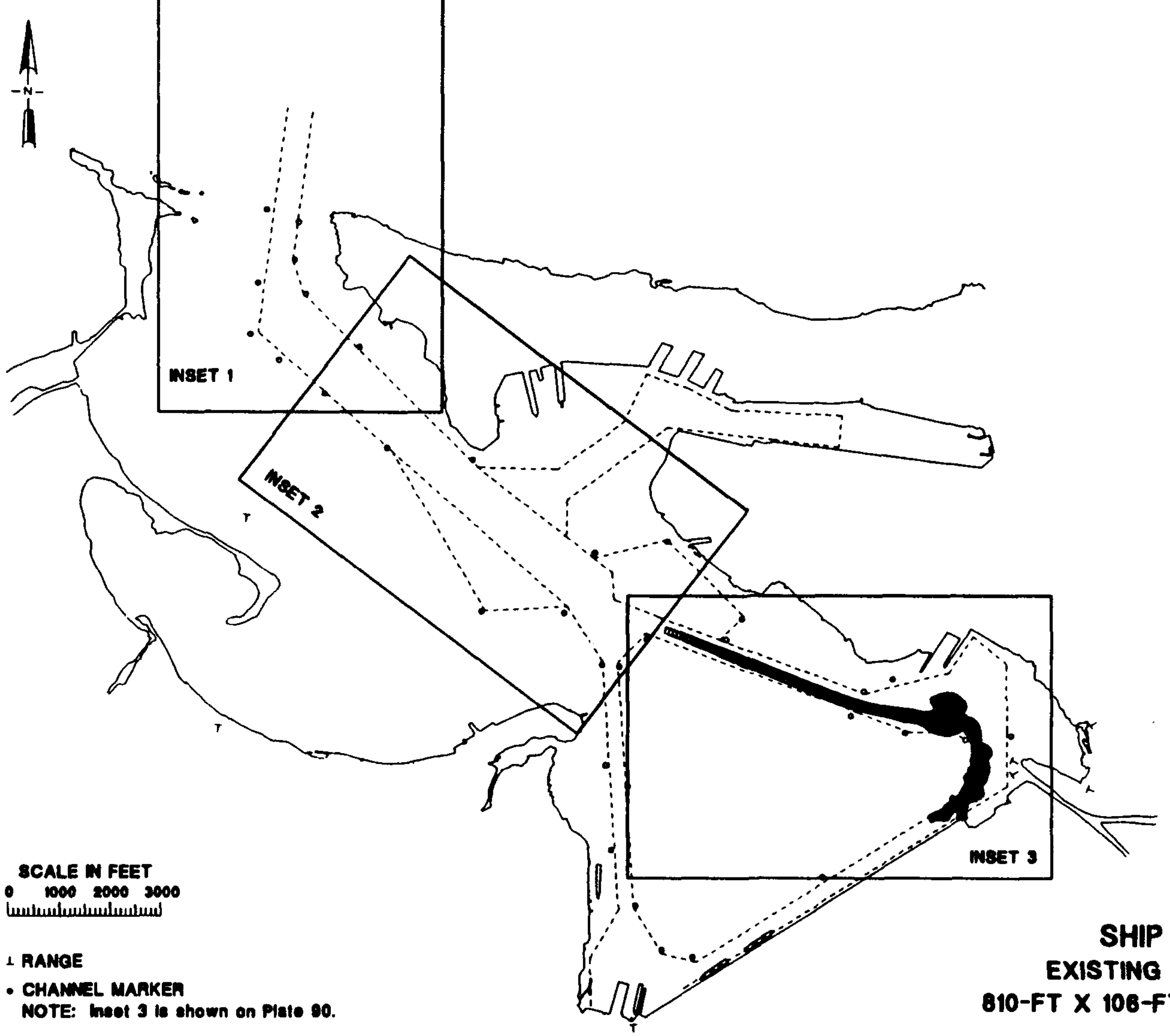


INSET 1
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000



INSET 2
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

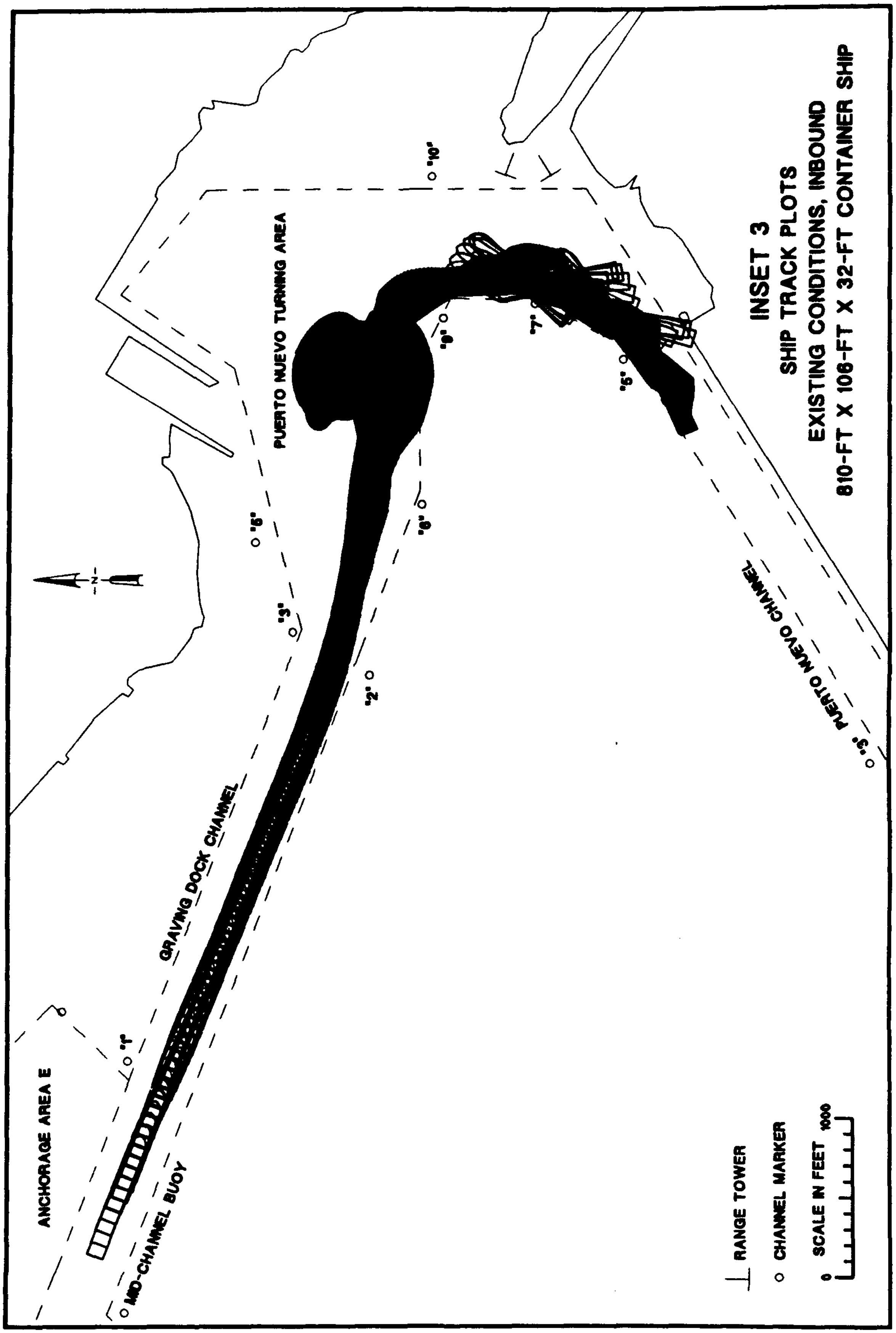

INSET 3
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000



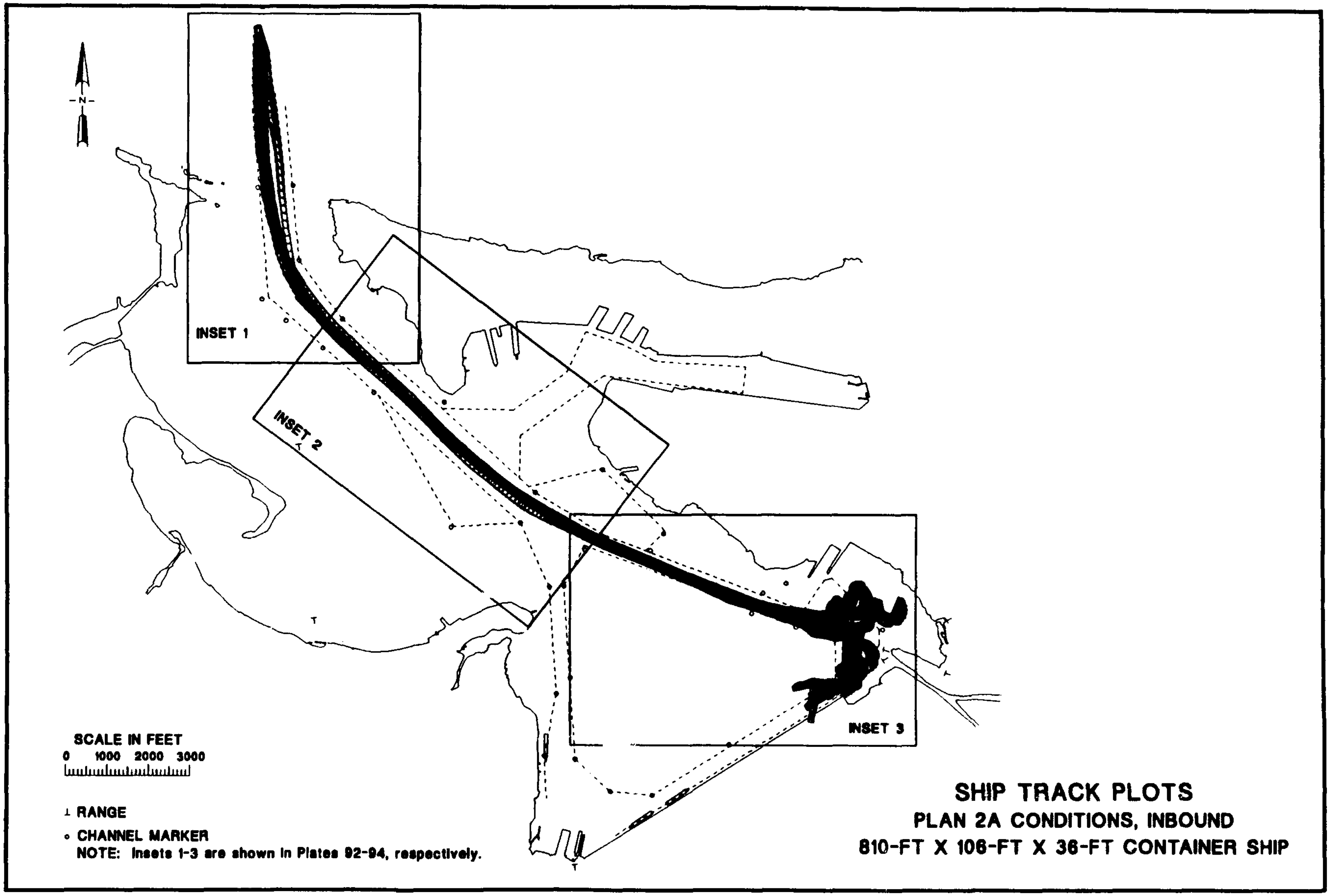
SCALE IN FEET
0 1000 2000 3000

⊥ RANGE
• CHANNEL MARKER
NOTE: Inset 3 is shown on Plate 90.

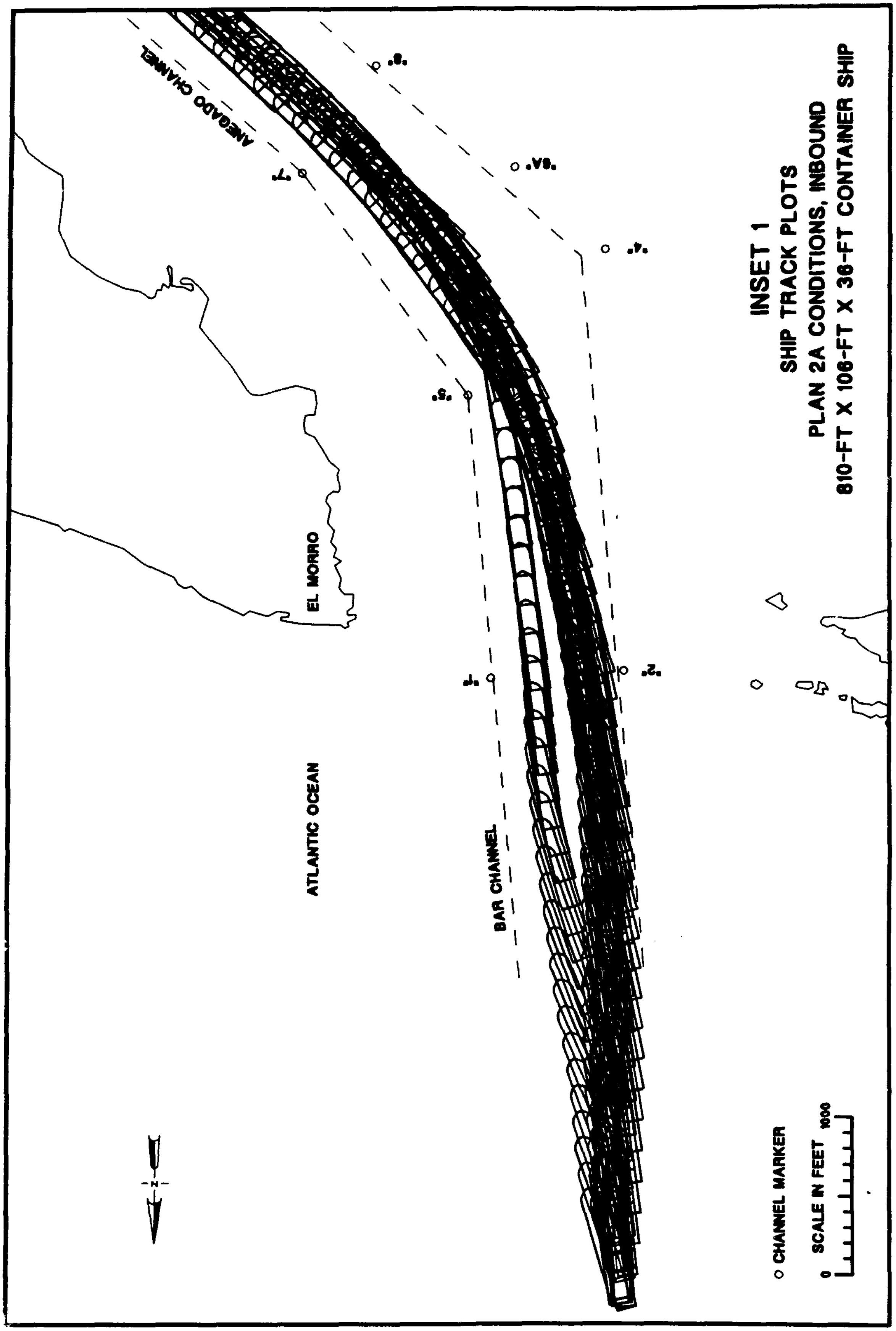
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP



INSET 3
SHIP TRACK PLOTS
EXISTING CONDITIONS, INBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
PUERTO NUEVO TURNING AREA
GRAVING DOCK CHANNEL
PUERTO NUEVO CHANNEL
ANCHORAGE AREA E
MID-CHANNEL BUOY
"1"
"2"
"3"
"4"
"5"
"6"
"7"
"8"
"9"
"10"
N
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000

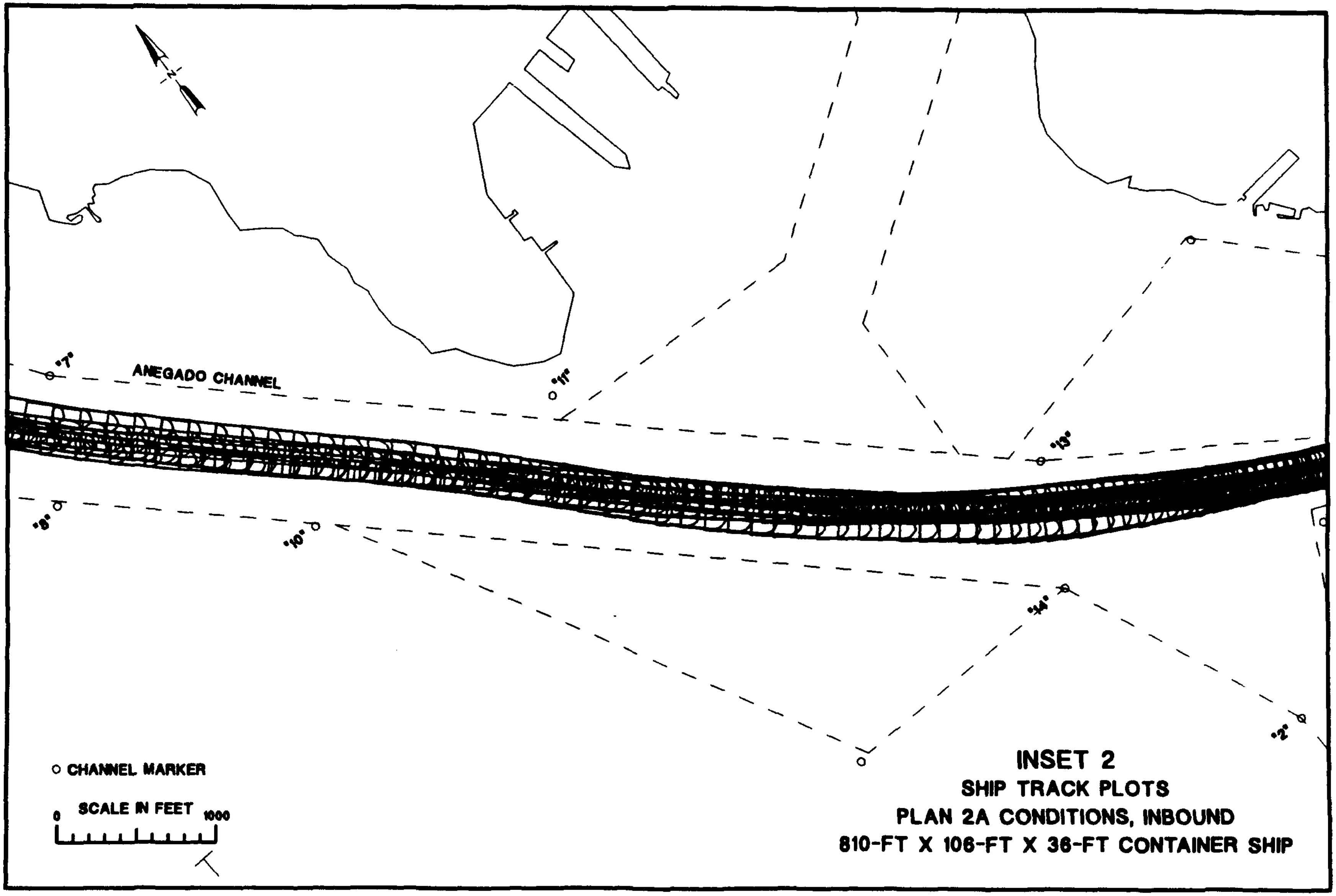


SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

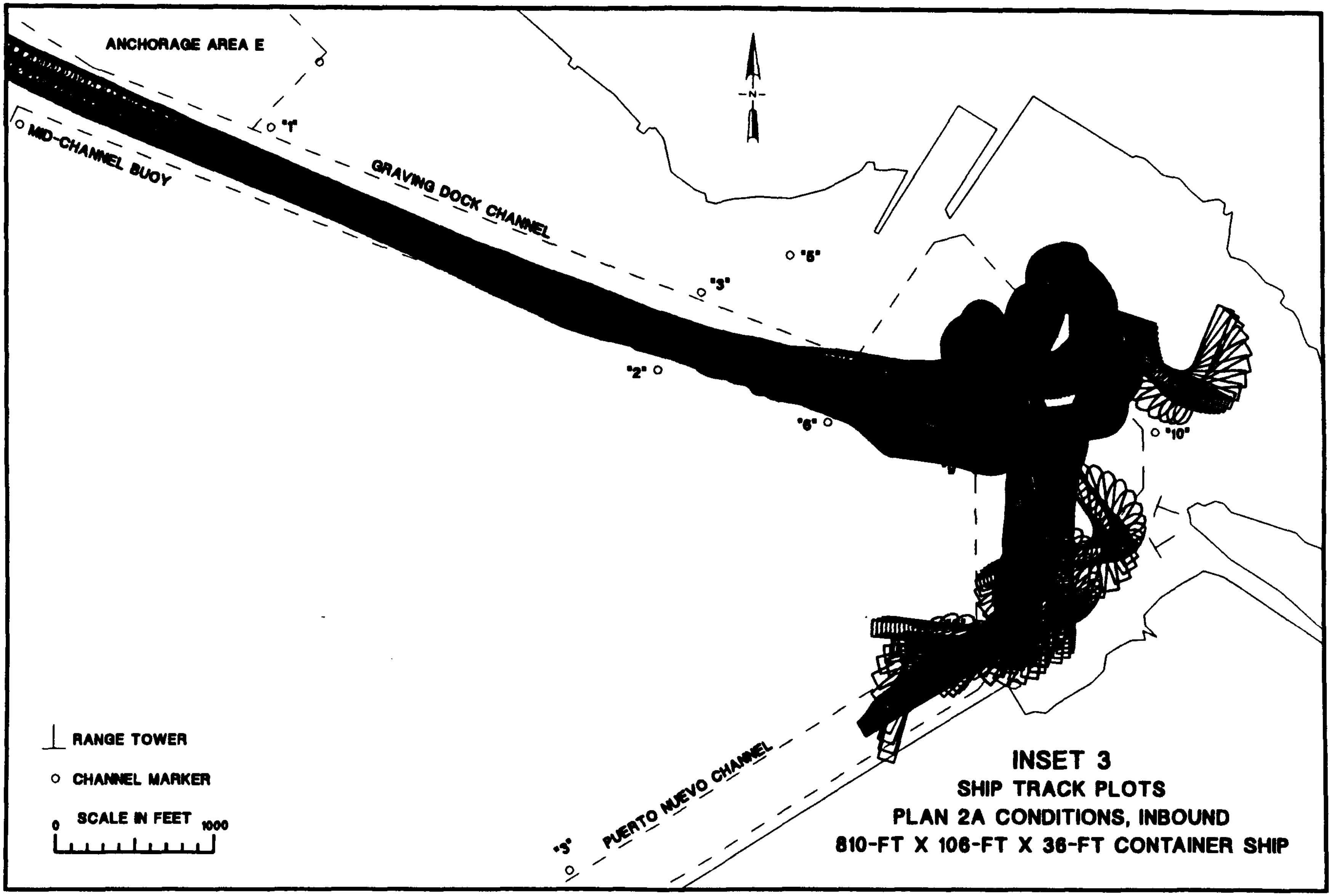


INSET 1
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
CHANNEL MARKER
SCALE IN FEET
0
1000
N

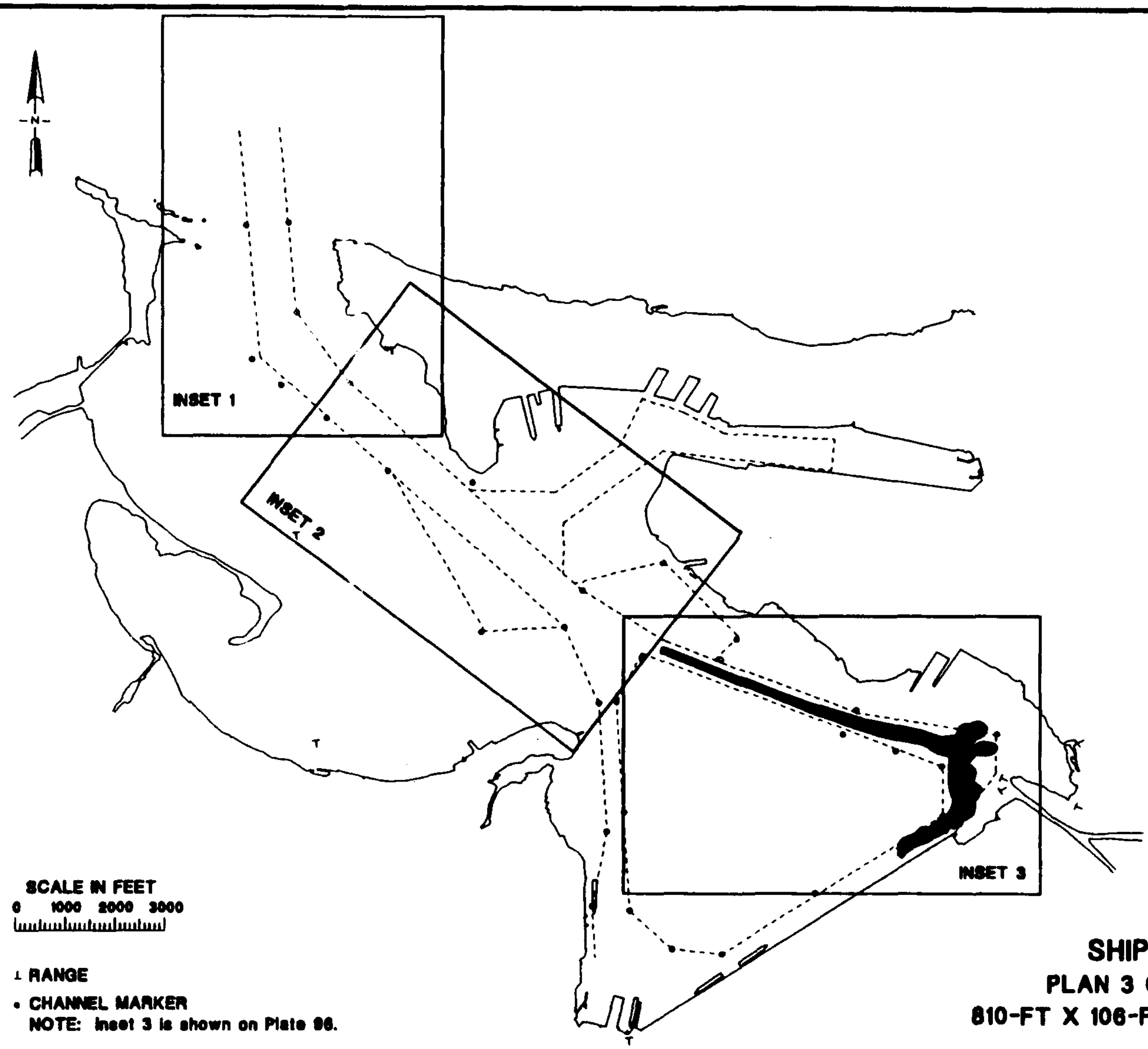
Plate 92



INSET 2
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 3
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



SHIP TRACK PLOTS
PLAN 3 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

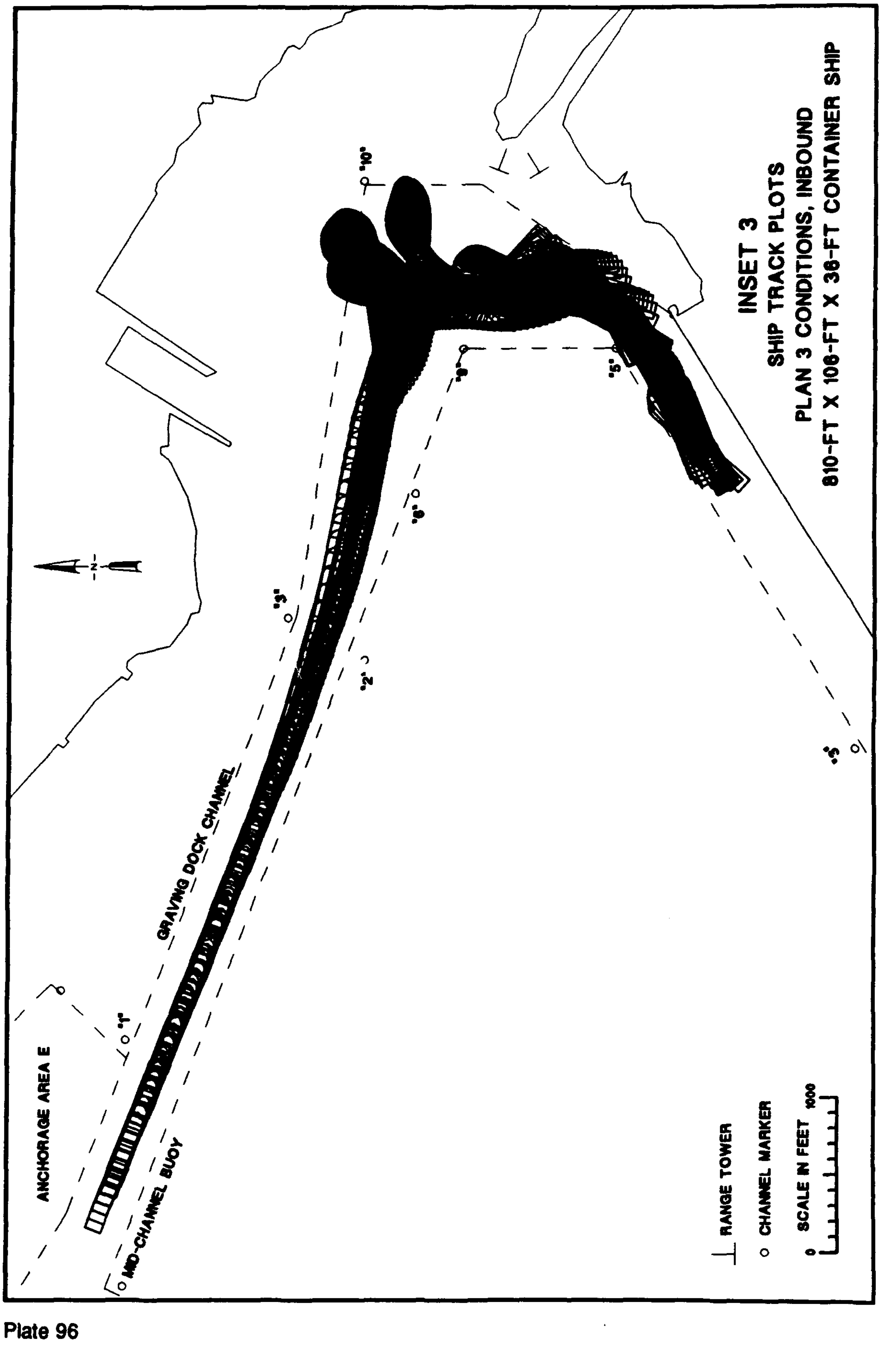
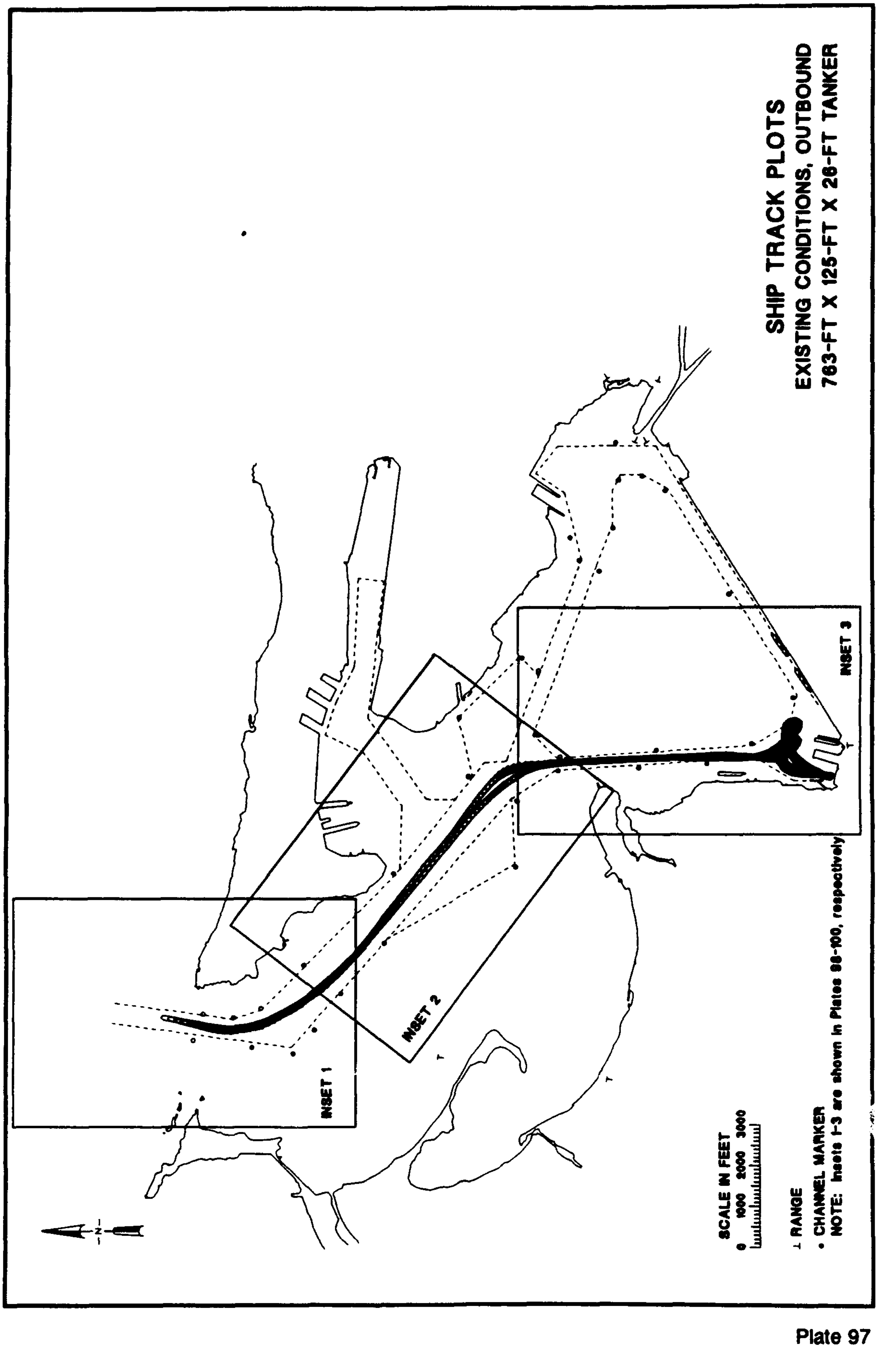
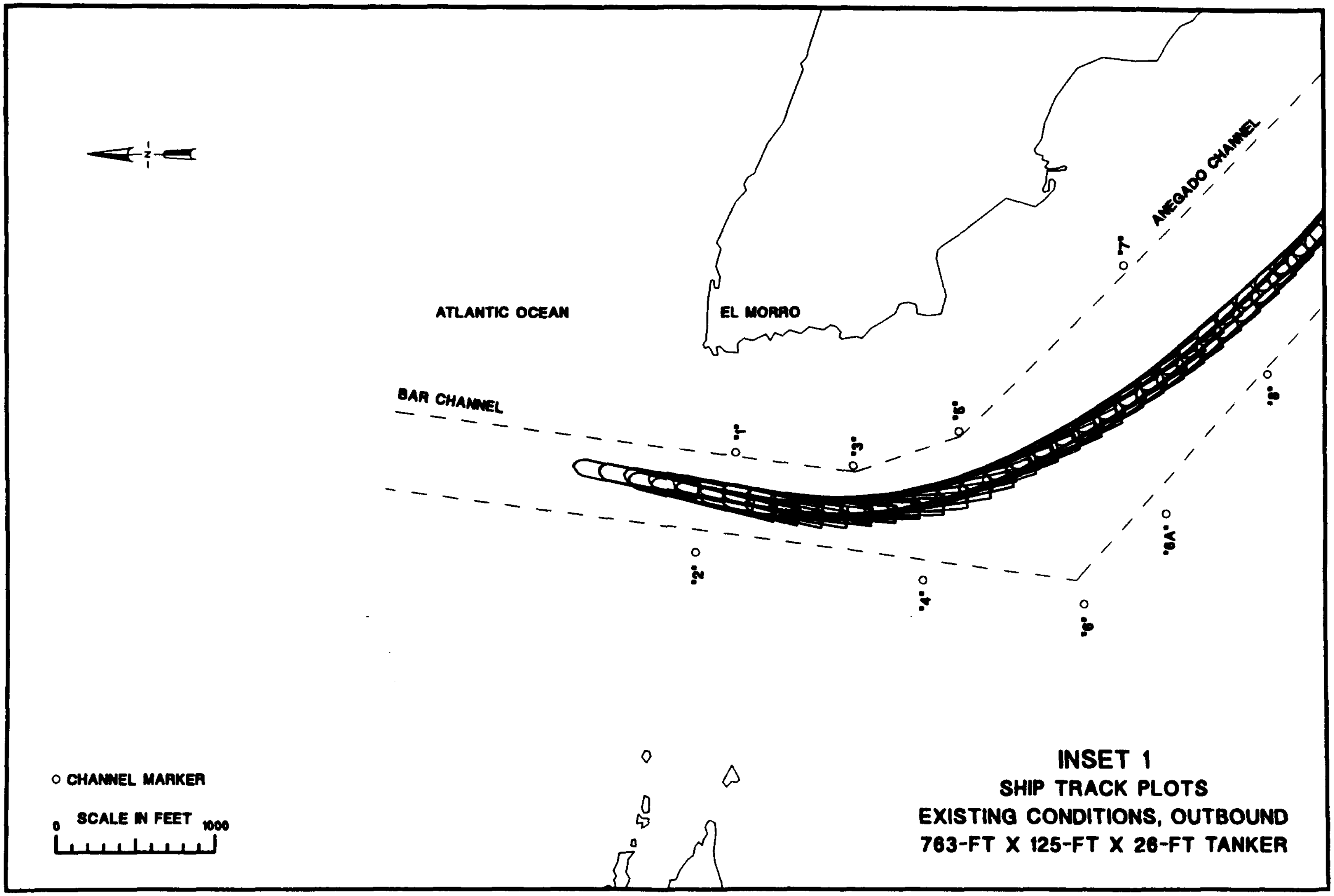

INSET 3
SHIP TRACK PLOTS
PLAN 3 CONDITIONS, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANCHORAGE AREA E
GRAVING DOCK CHANNEL
MID-CHANNEL BUOY
"1"
"2"
"3"
"5"
"6"
"8"
"10"
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000

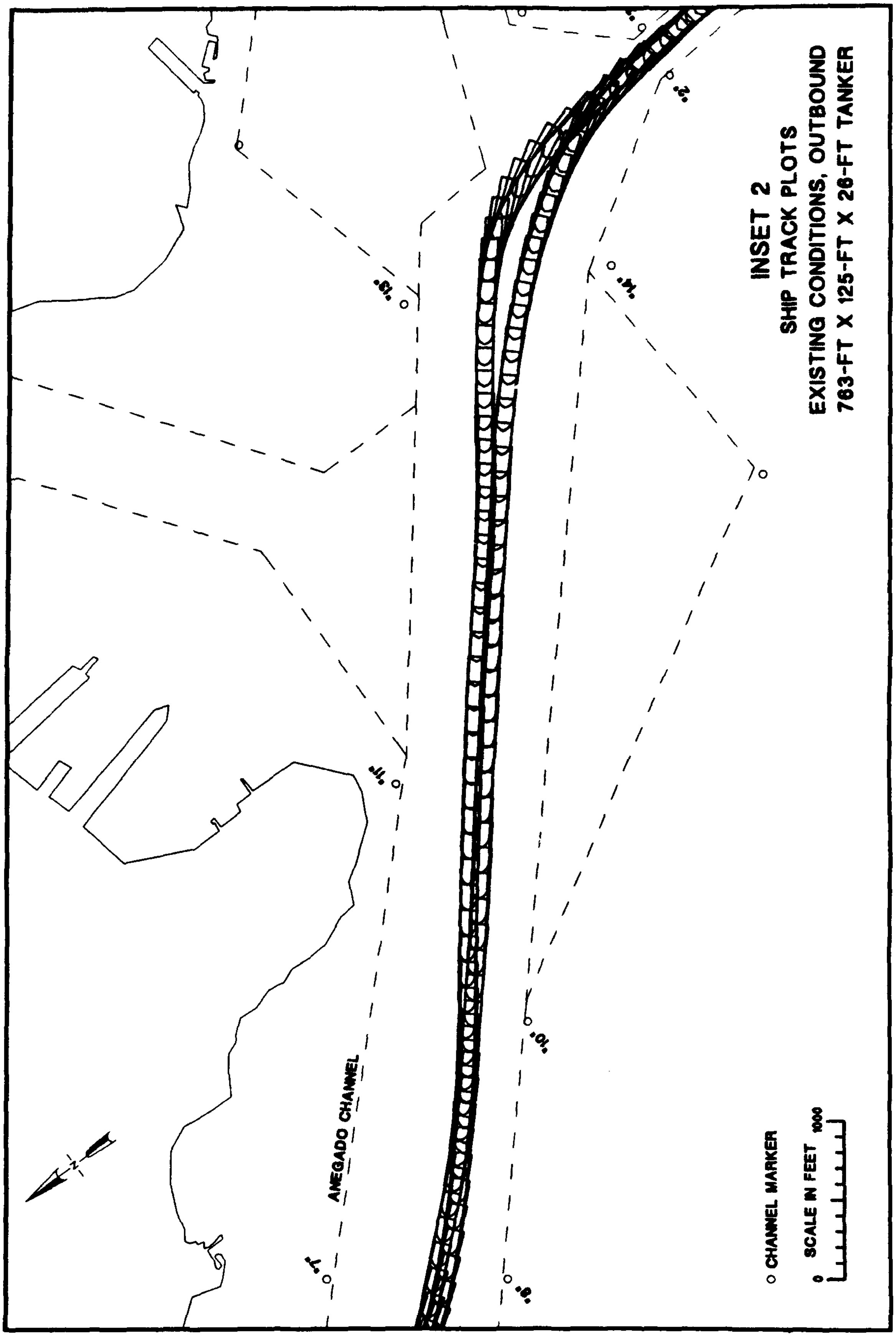
Plate 96

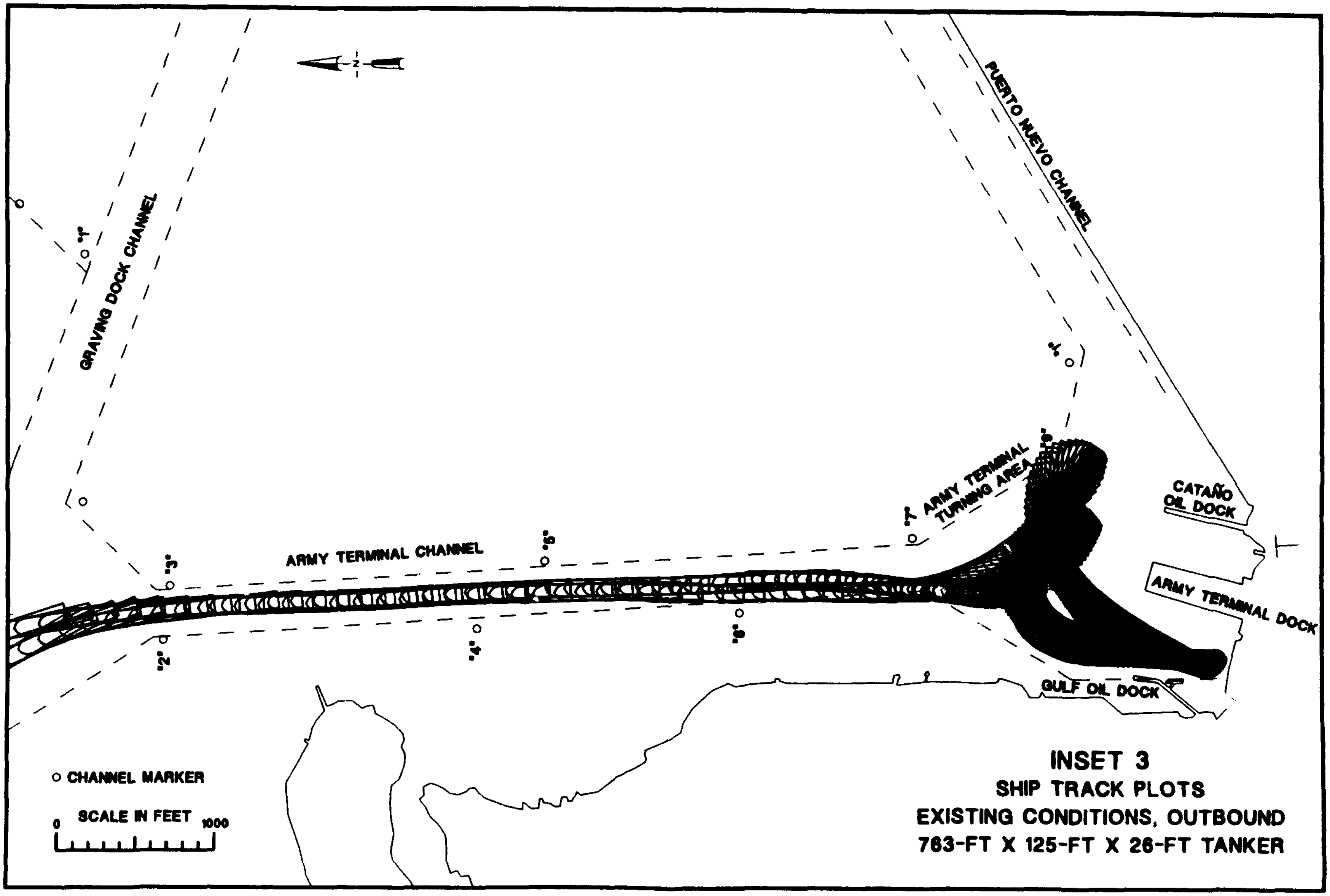


SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

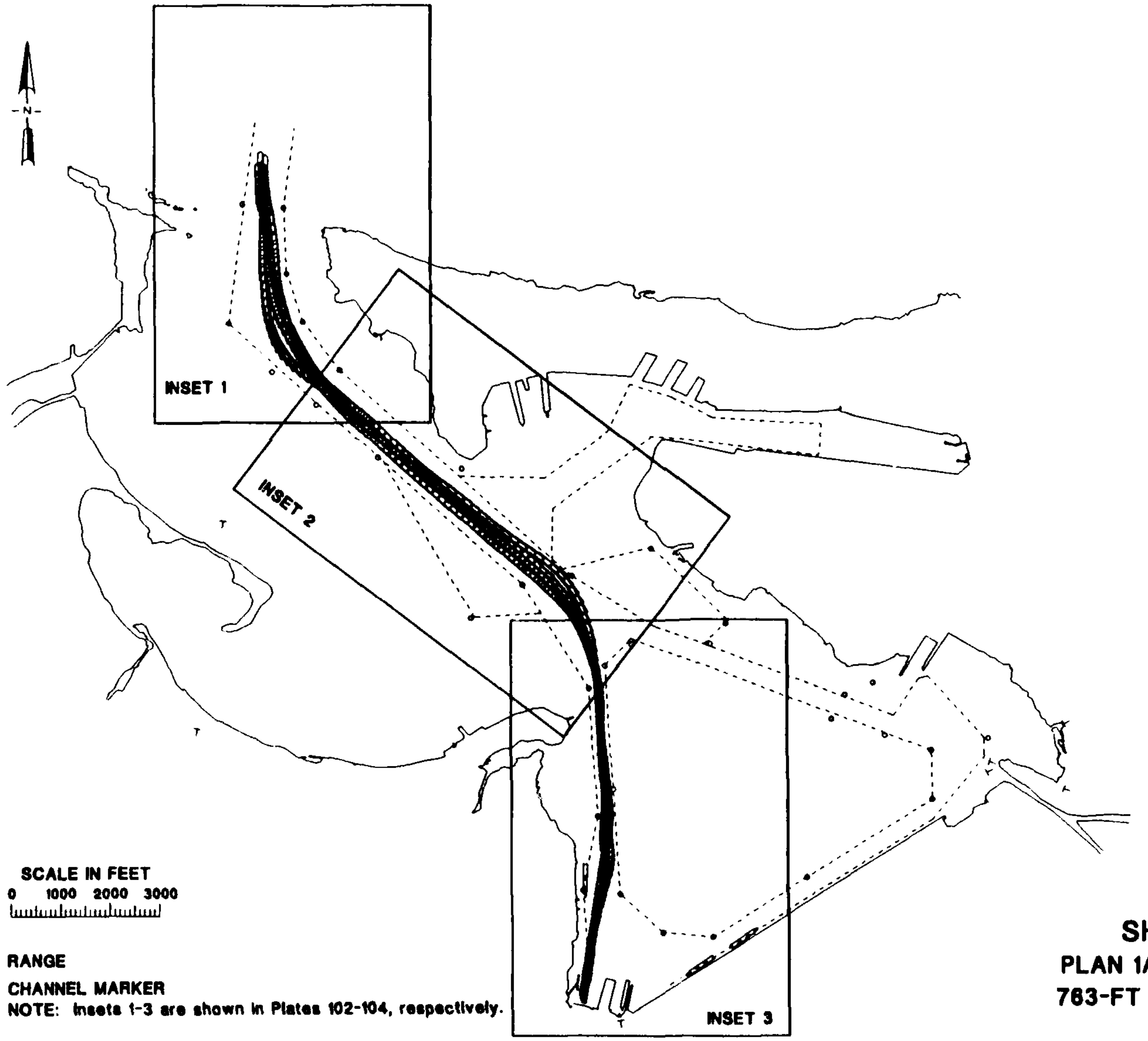


INSET 1
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

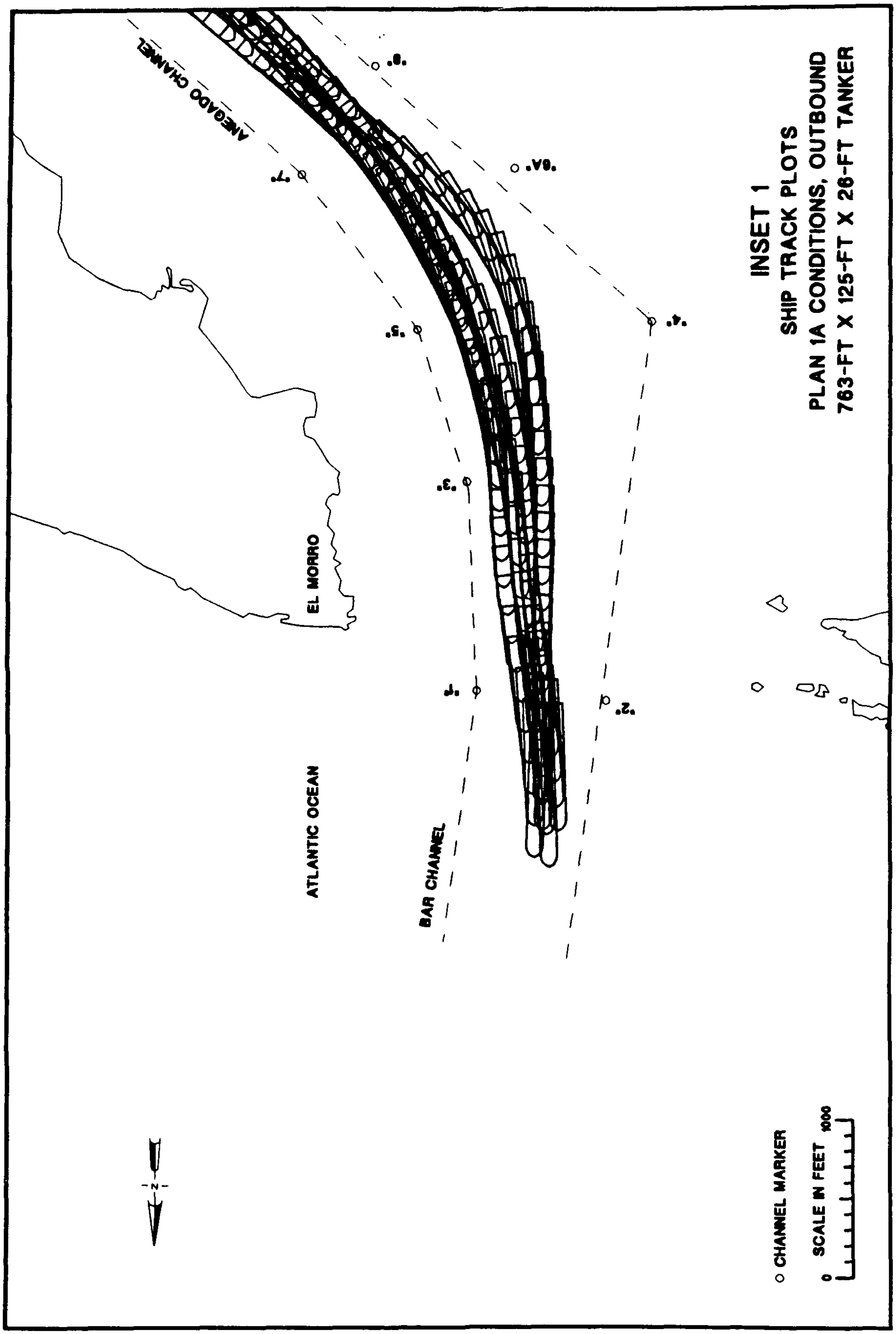

INSET 2
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
CHANNEL MARKER
SCALE IN FEET
0
1000
ANEGADO CHANNEL

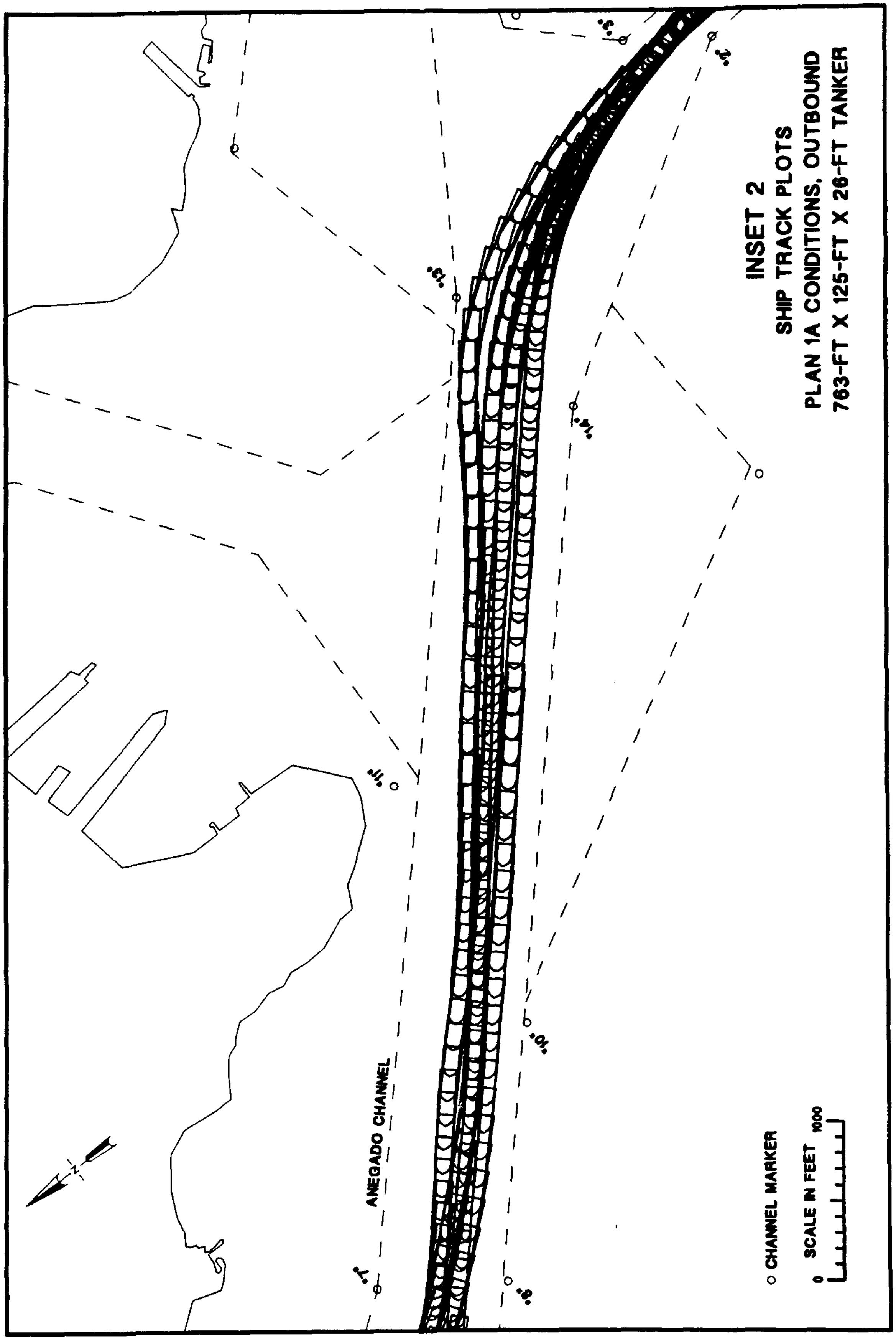


INSET 3
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

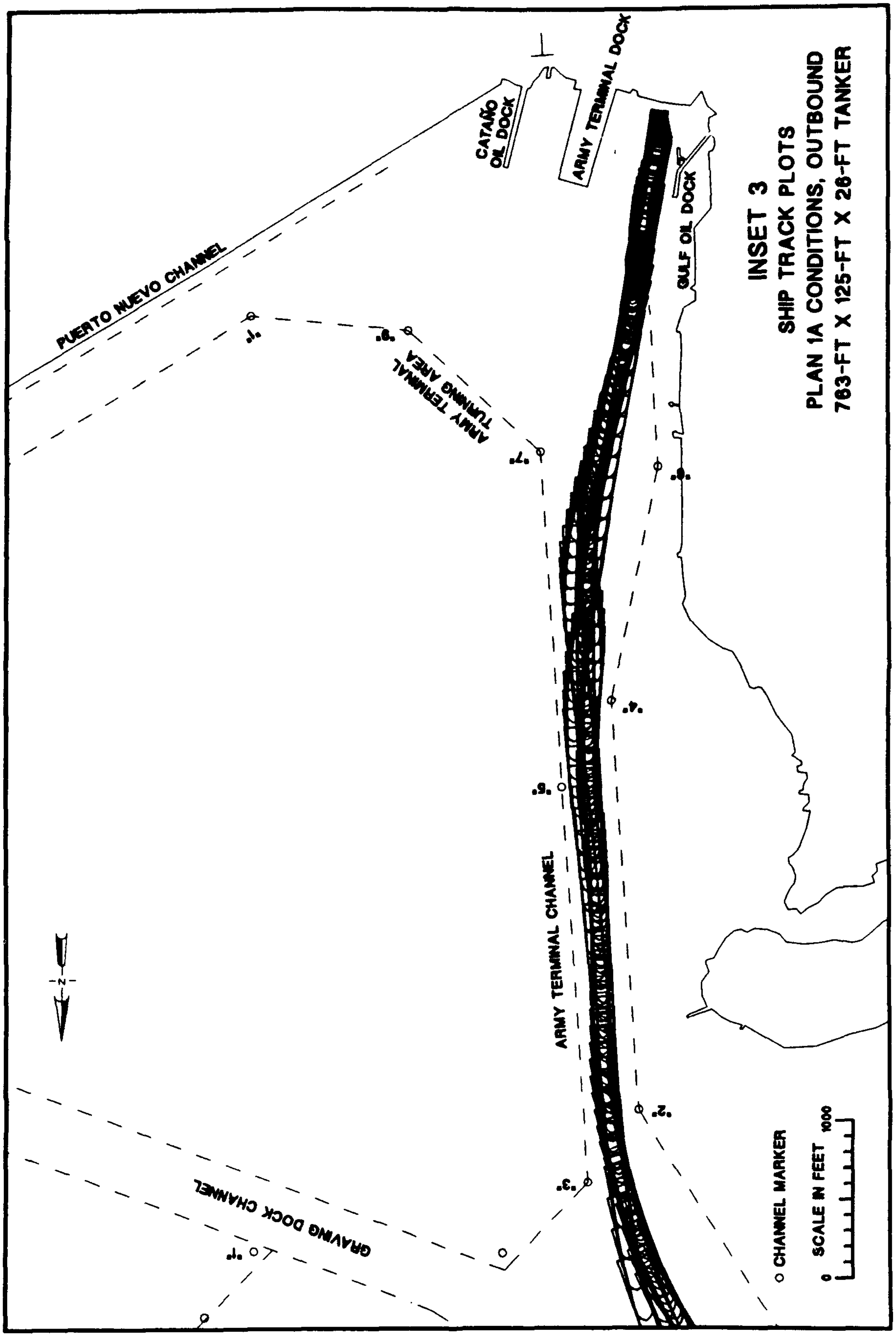


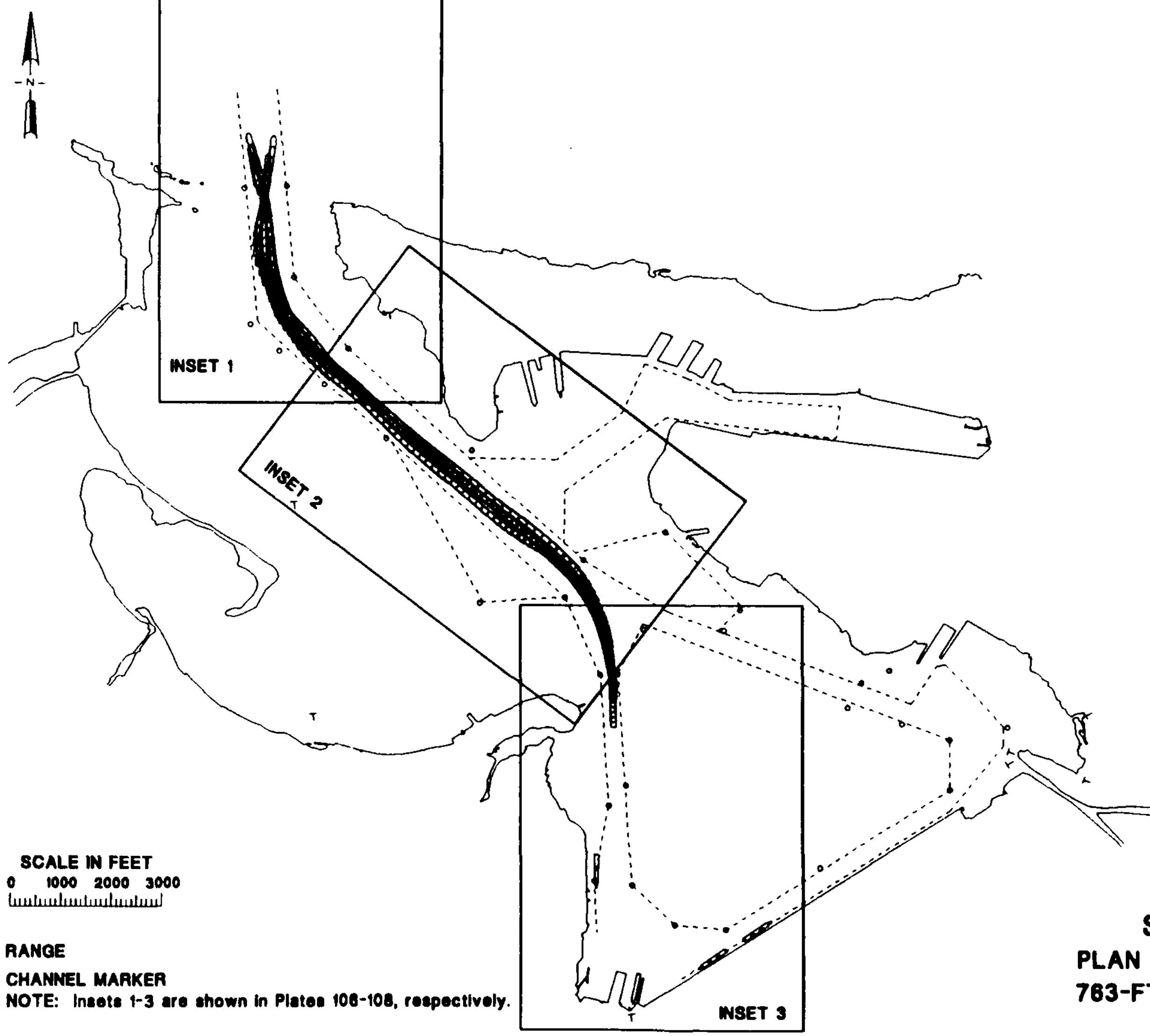
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER


INSET 1
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
ANEGADO CHANNEL
EL MORRO
ATLANTIC OCEAN
BAR CHANNEL
"1"
"2"
"3"
"4"
"5"
"6A"
"7"
"8"
N
CHANNEL MARKER
SCALE IN FEET
0
1000



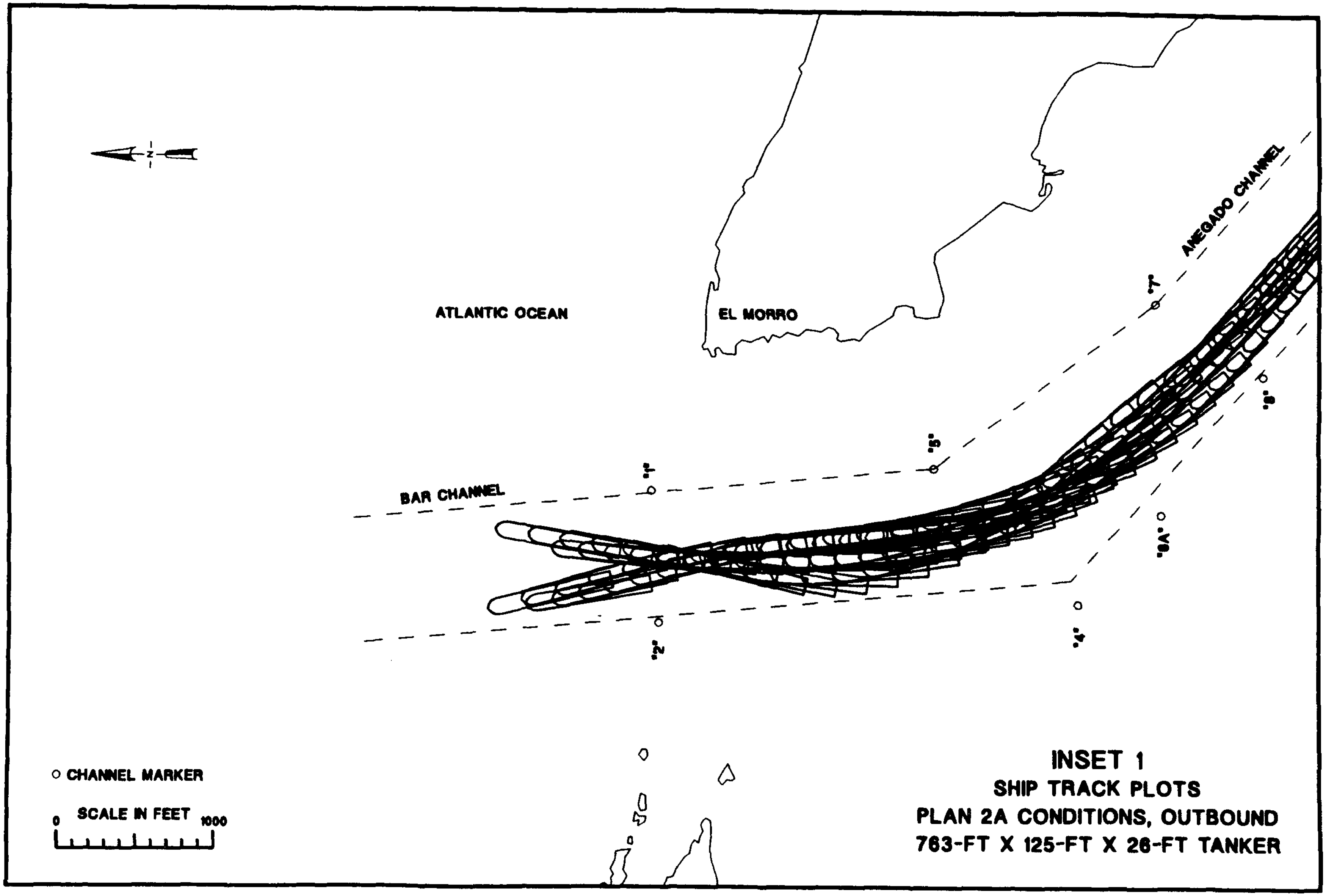
INSET 2
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER


INSET 3
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
PUERTO NUEVO CHANNEL
CATAÑO OIL DOCK
ARMY TERMINAL DOCK
GULF OIL DOCK
ARMY TERMINAL TURNING AREA
ARMY TERMINAL CHANNEL
GRAVING DOCK CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000

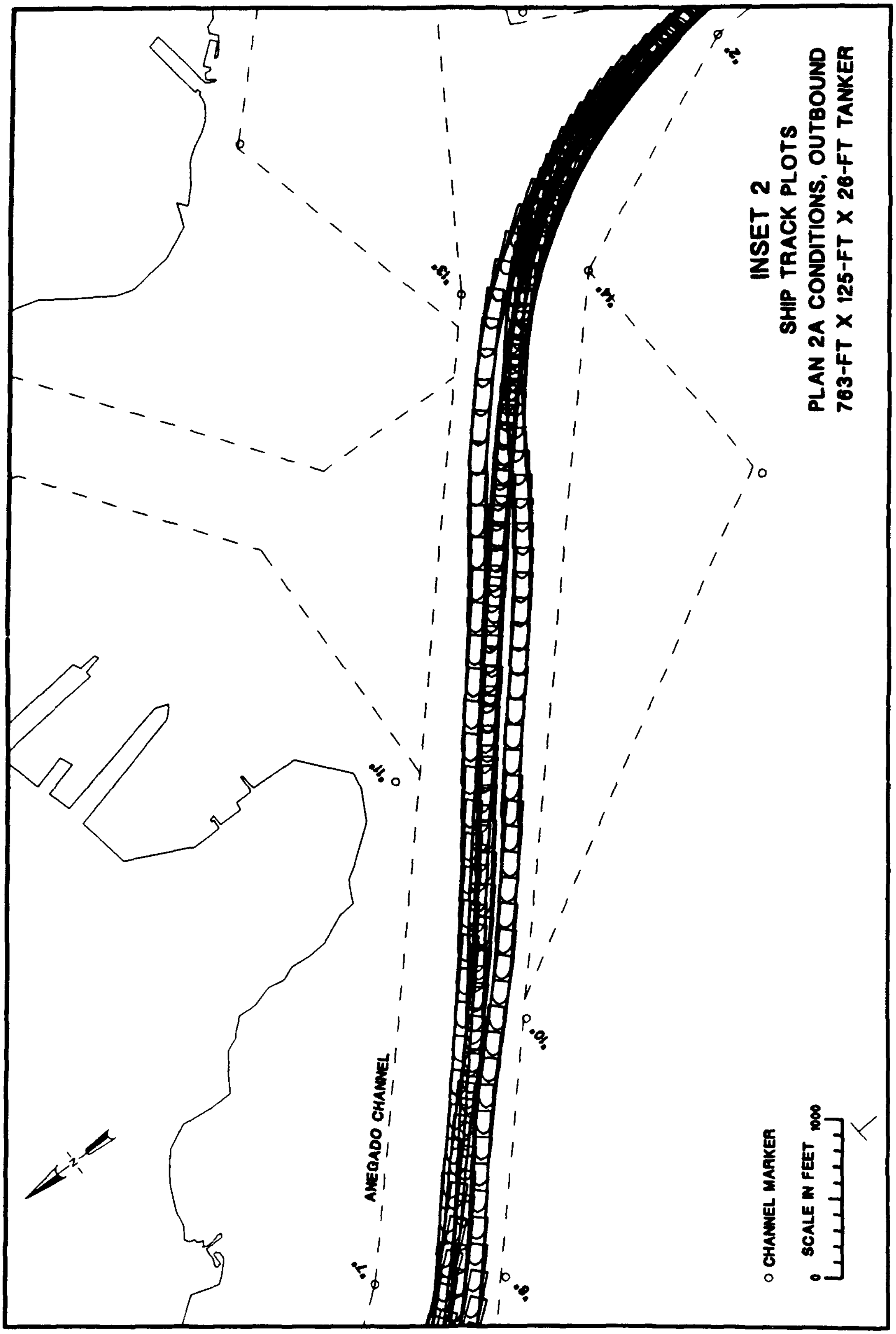


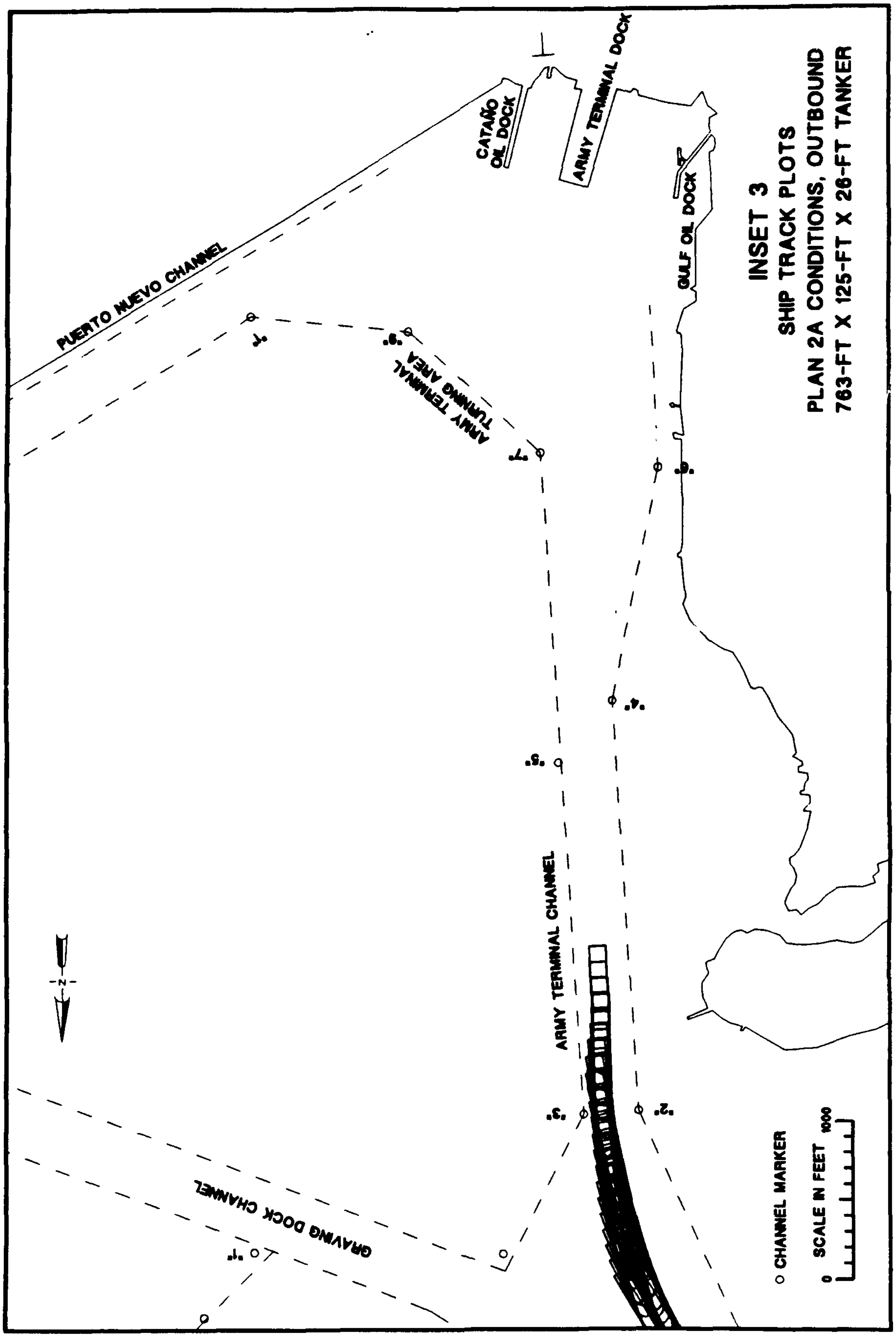
⊥ RANGE
∘ CHANNEL MARKER
NOTE: Insets 1-3 are shown in Plates 106-108, respectively.

SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER

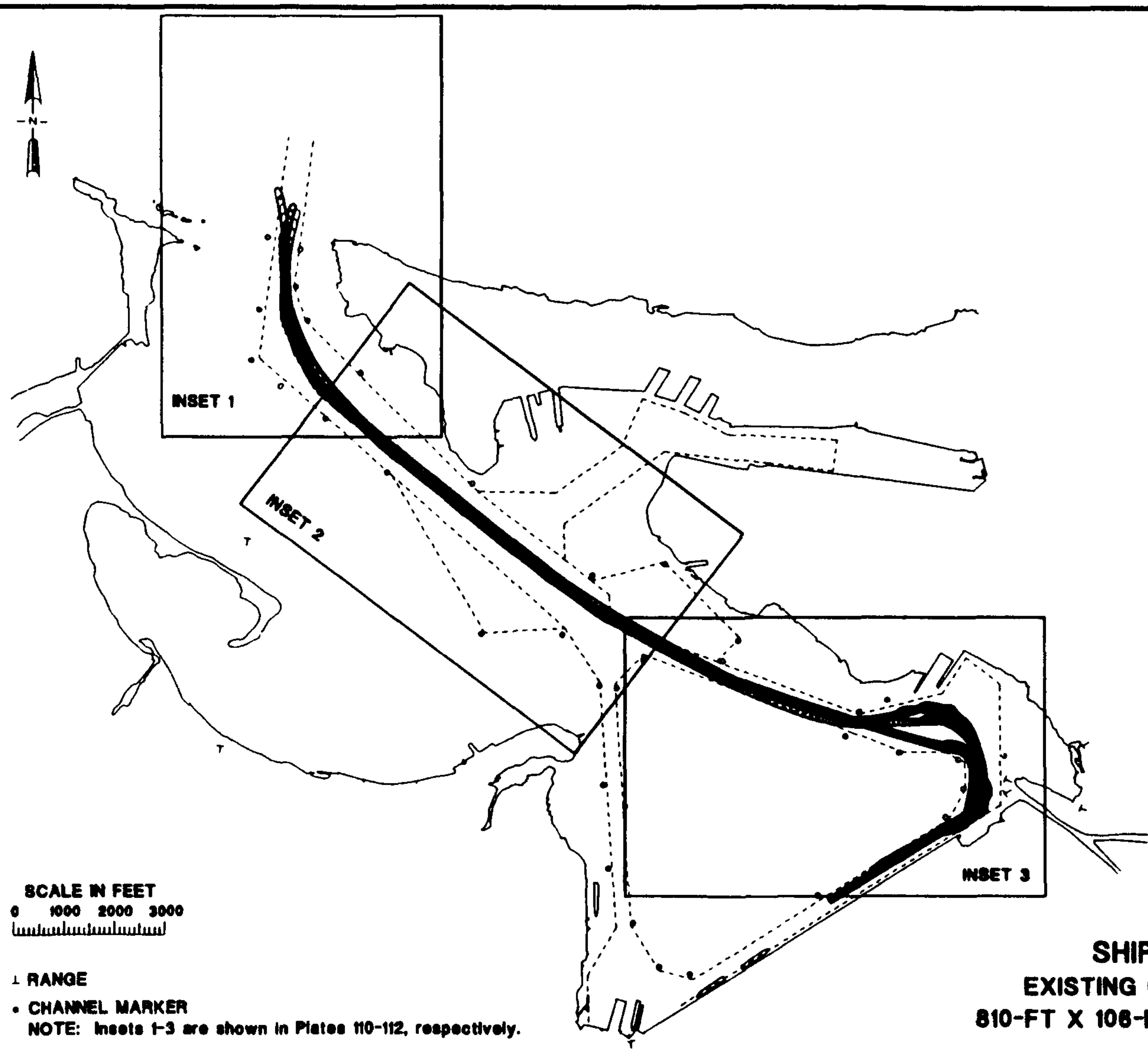


INSET 1
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER


INSET 2
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER
ANEGADO CHANNEL
N
○ CHANNEL MARKER
SCALE IN FEET
0
1000



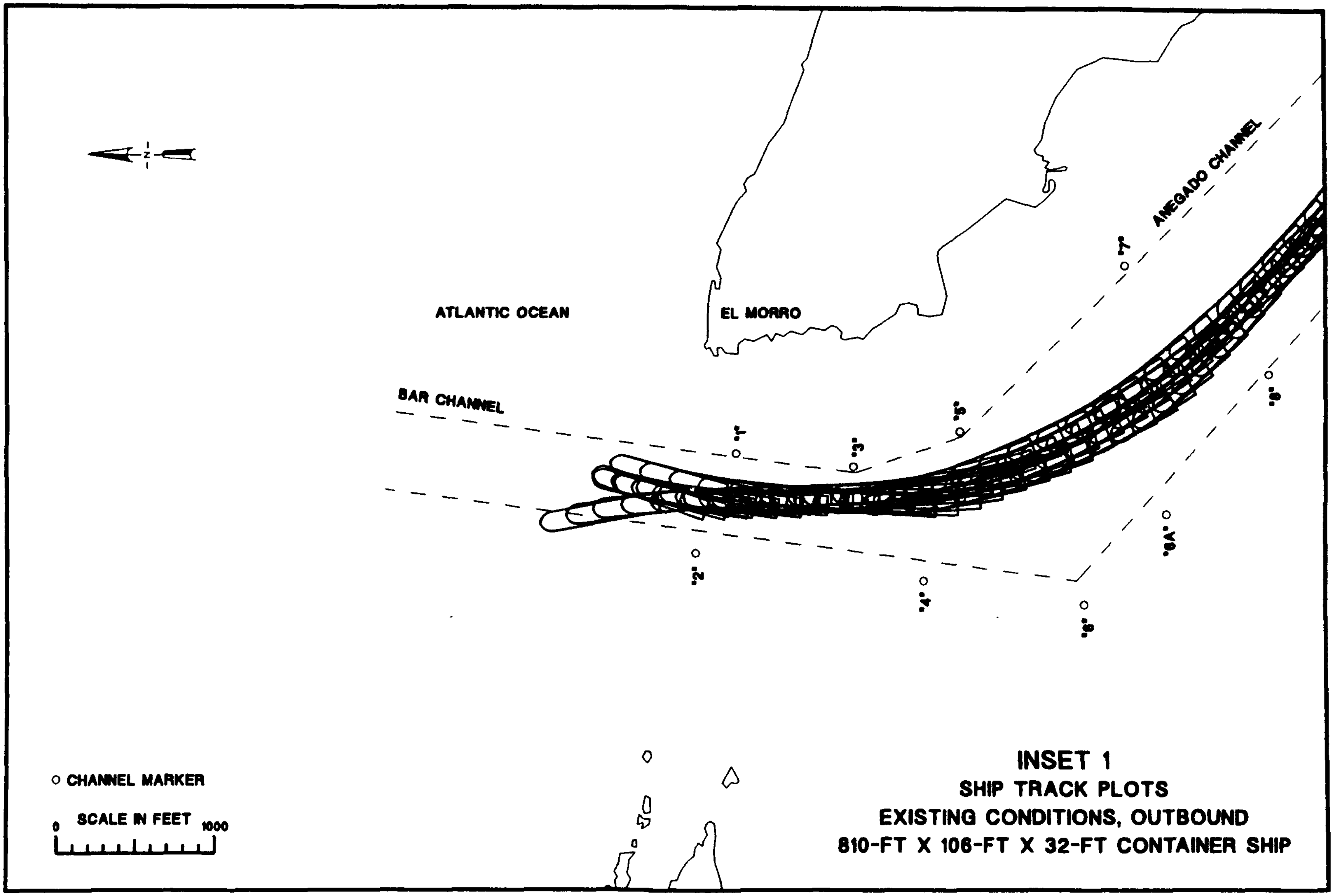
INSET 3
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
763-FT X 125-FT X 26-FT TANKER



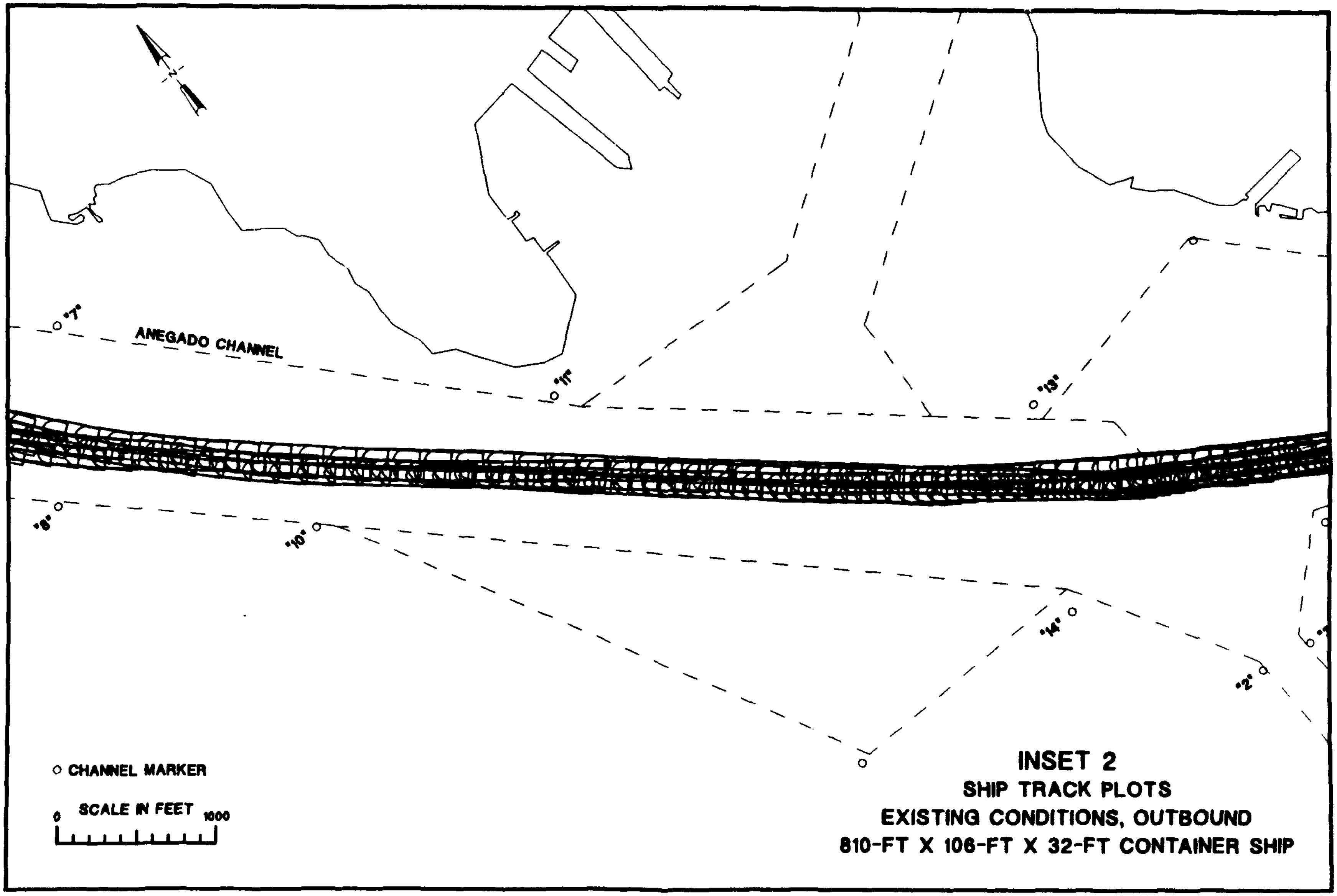
SCALE IN FEET
0 1000 2000 3000

⊥ RANGE
• CHANNEL MARKER
NOTE: Insets 1-3 are shown in Plates 110-112, respectively.

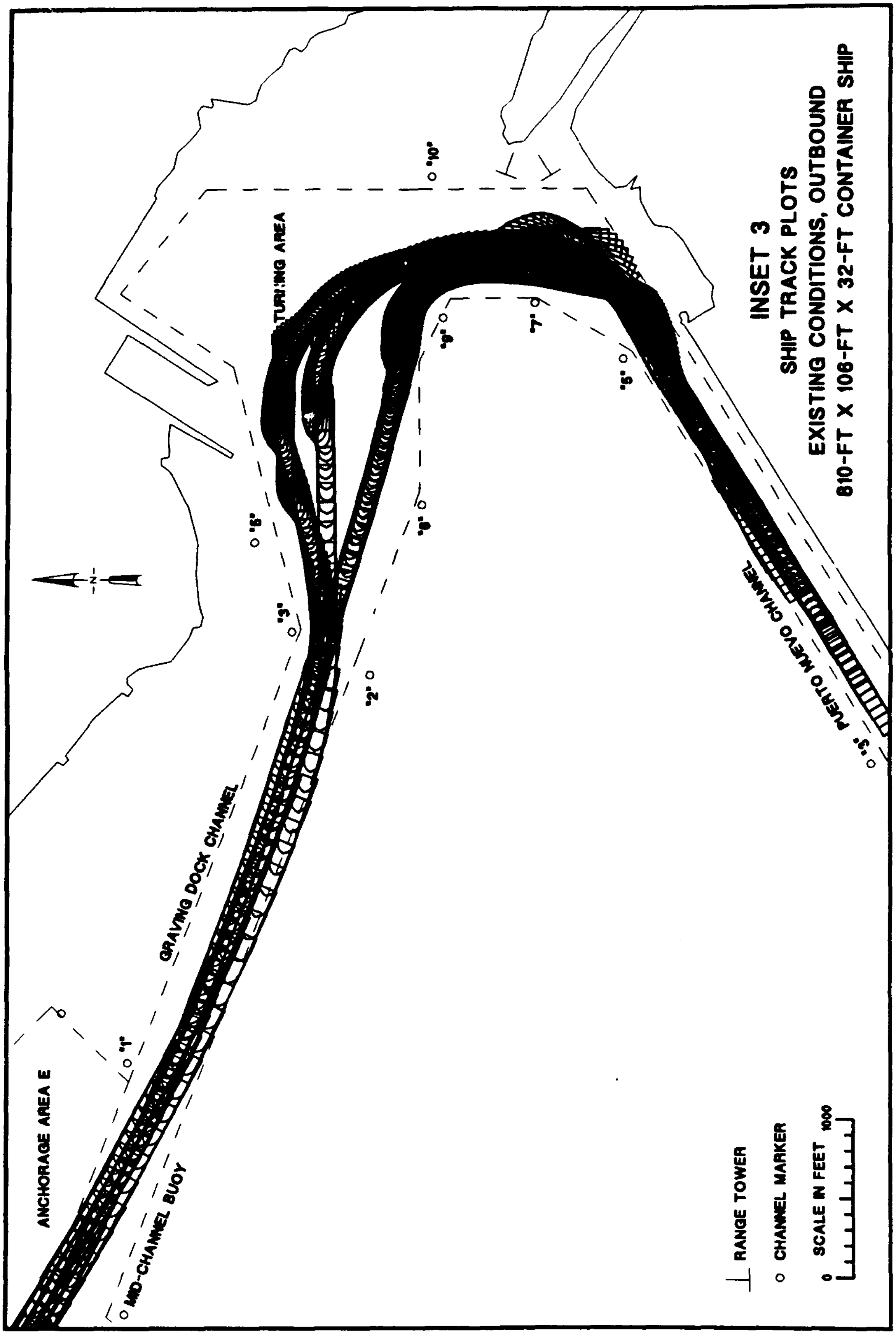
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

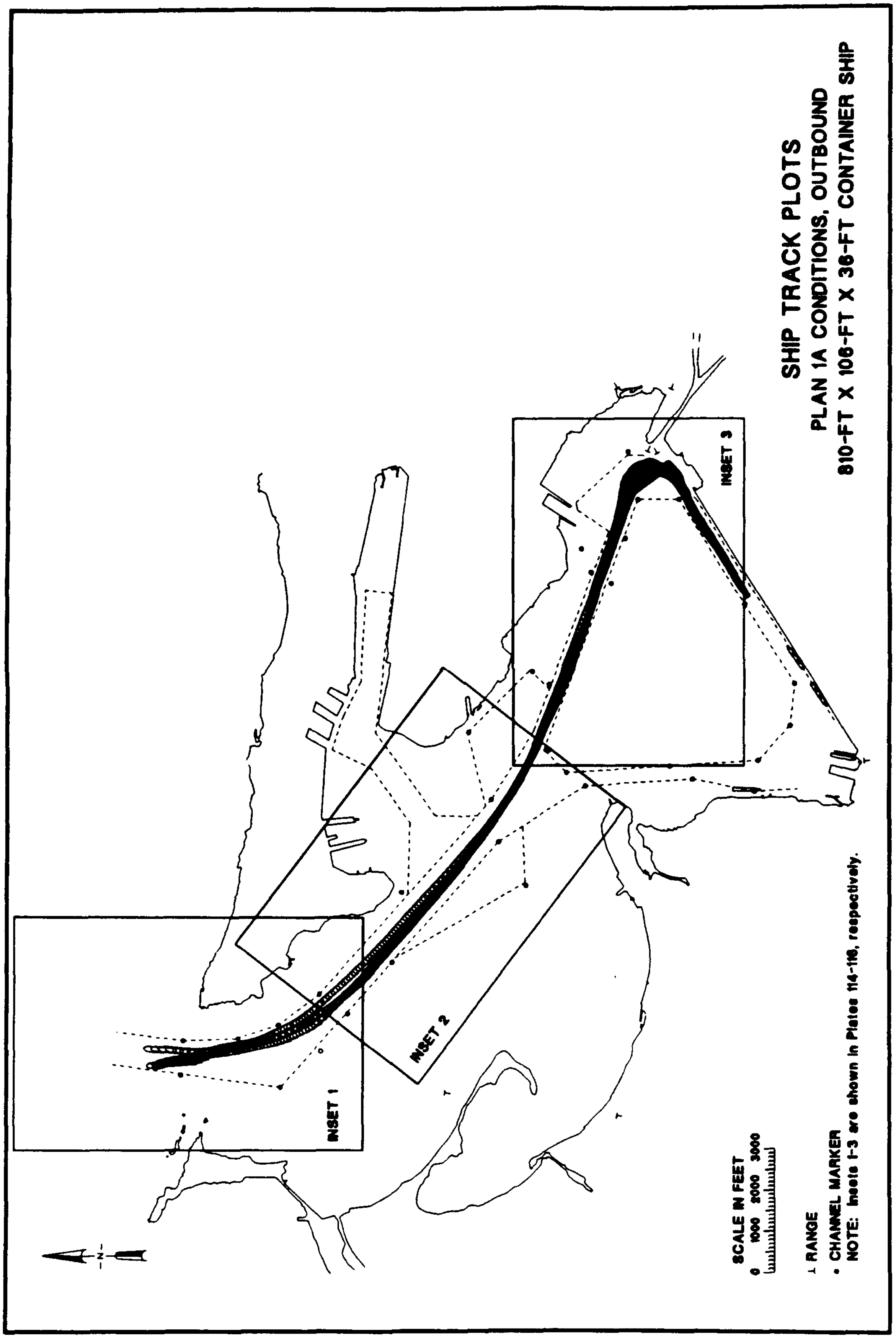


INSET 1
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

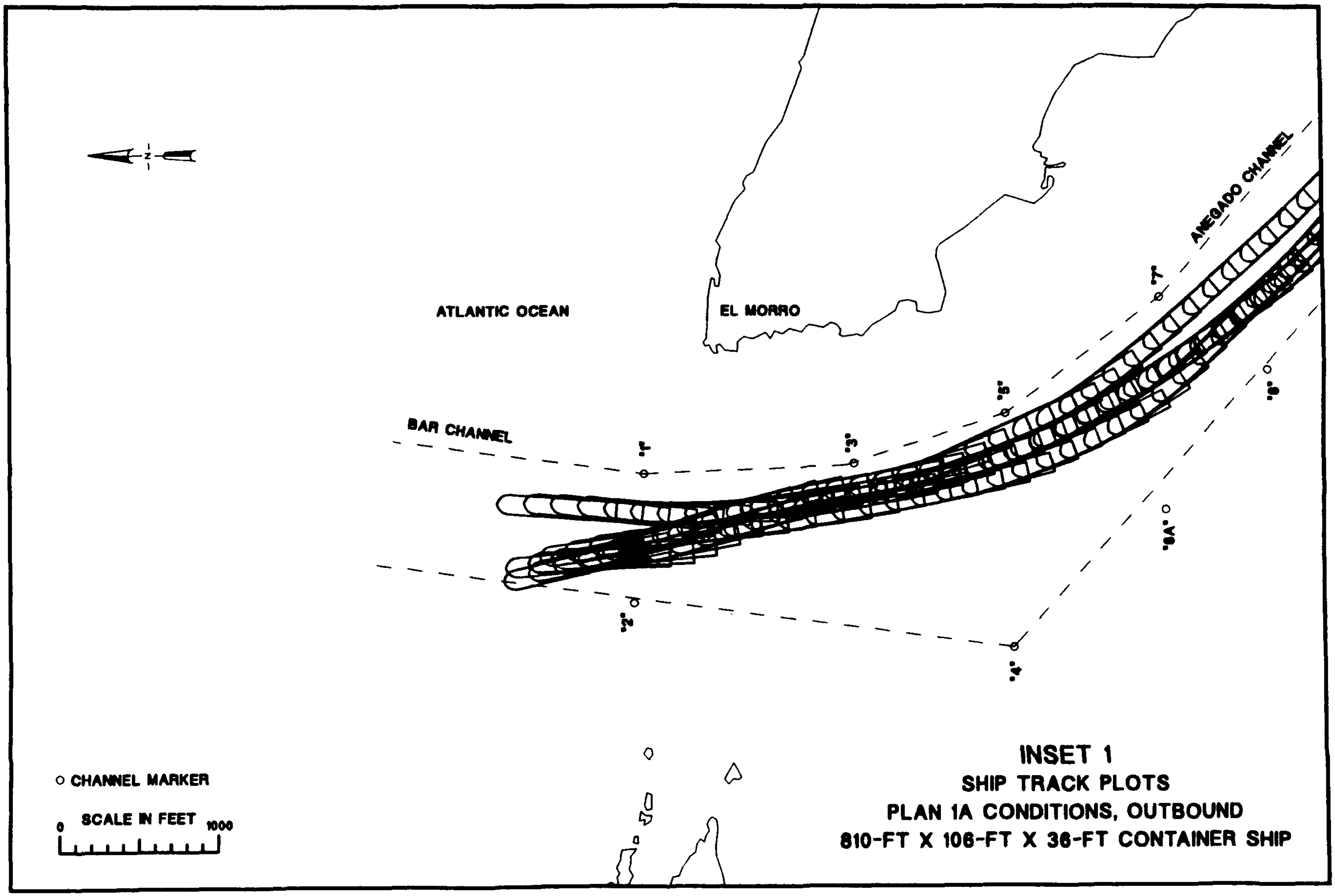


INSET 2
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP

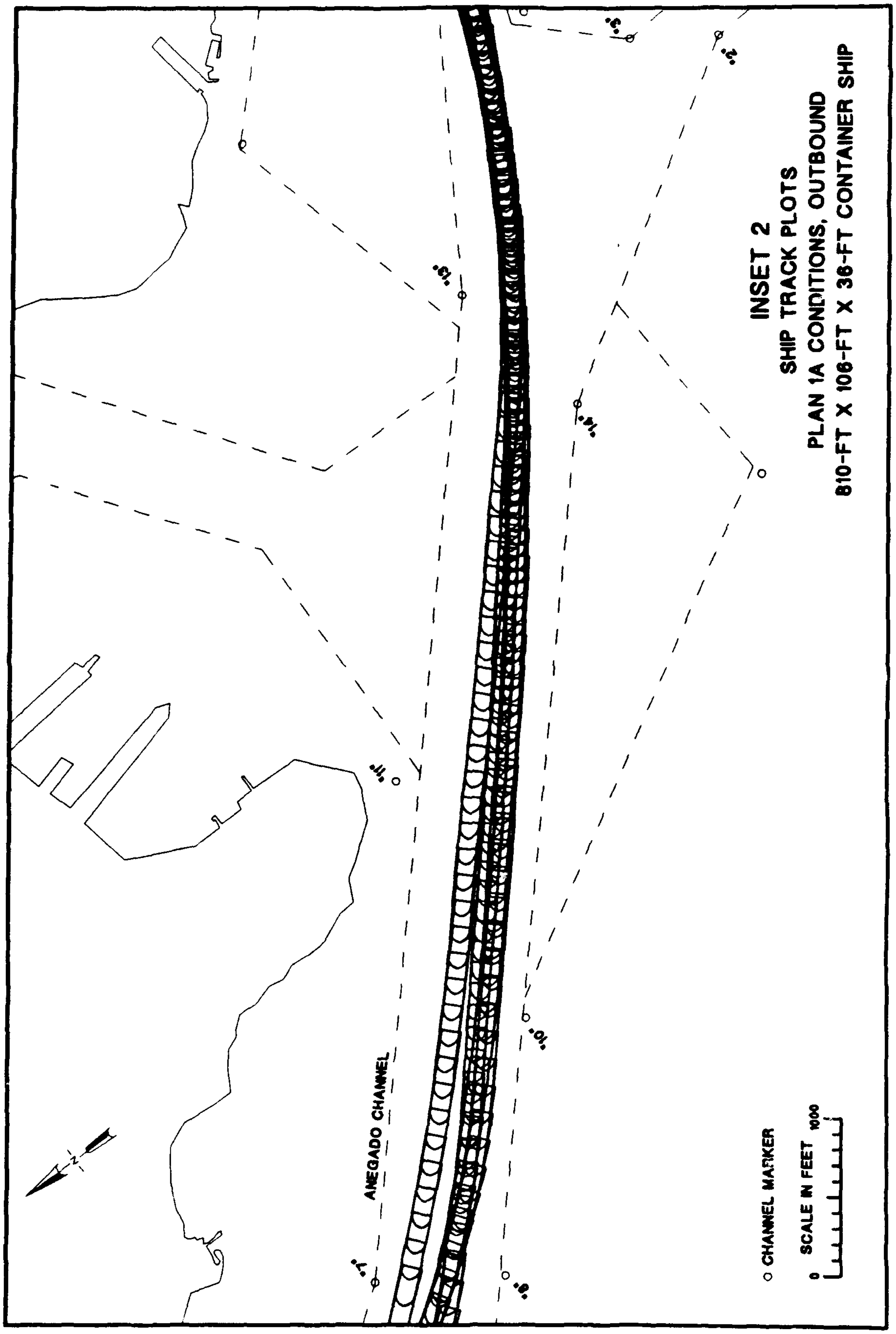

INSET 3
SHIP TRACK PLOTS
EXISTING CONDITIONS, OUTBOUND
810-FT X 106-FT X 32-FT CONTAINER SHIP
ANCHORAGE AREA E
MID-CHANNEL BUOY
GRAVING DOCK CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
"1"
"2"
"3"
"7"
"10"
N
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000



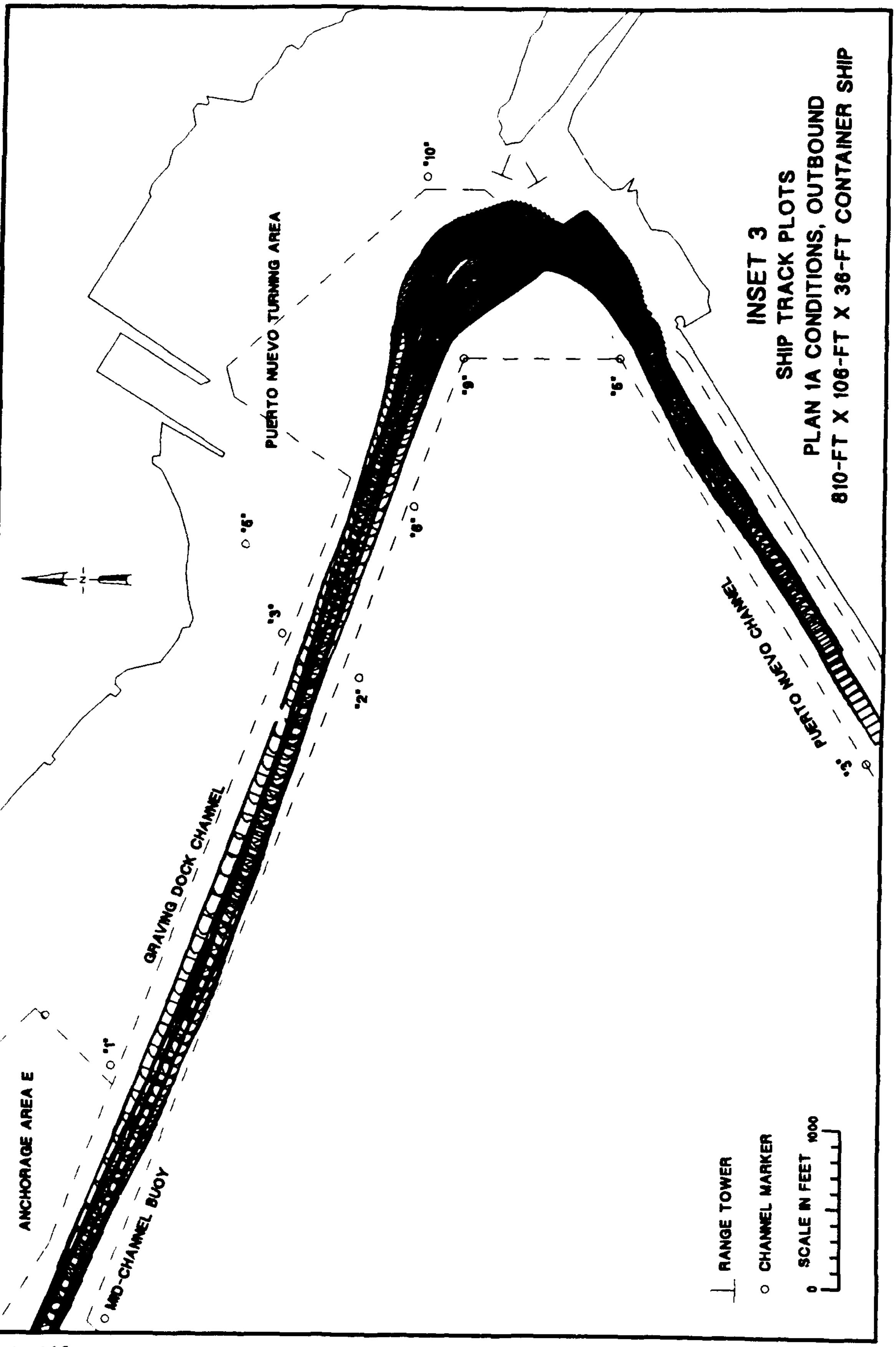
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

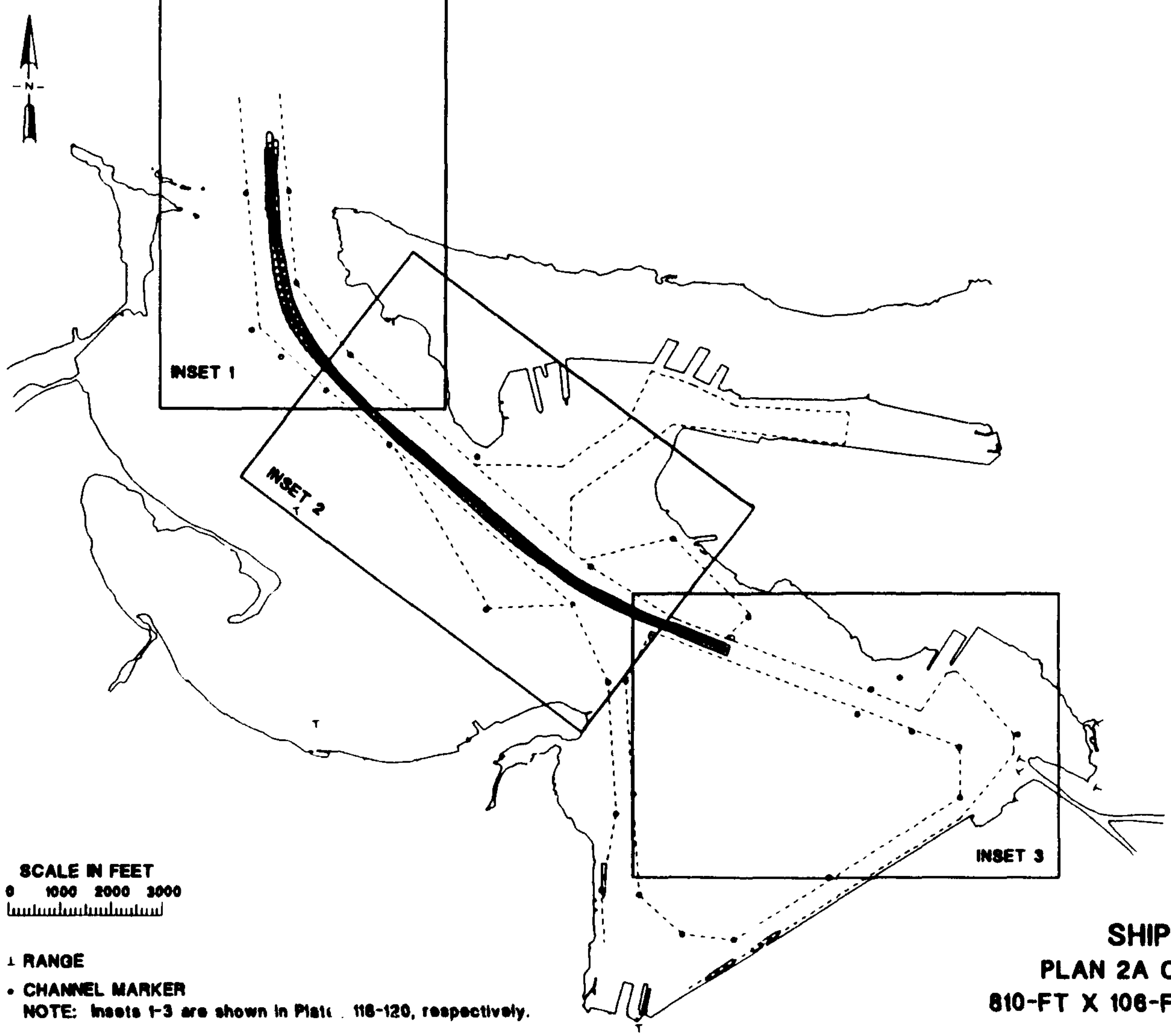


INSET 1
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

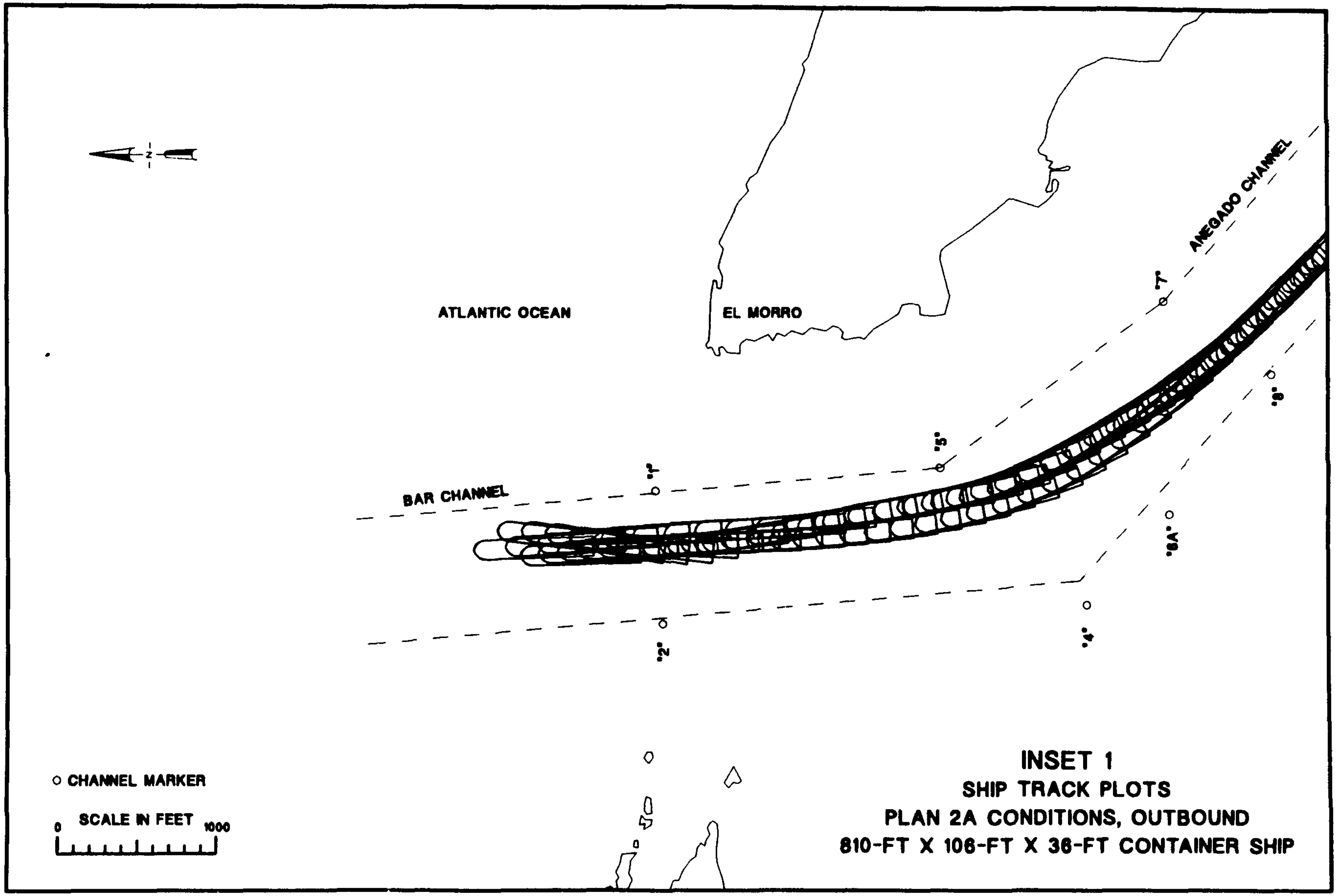


INSET 2
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

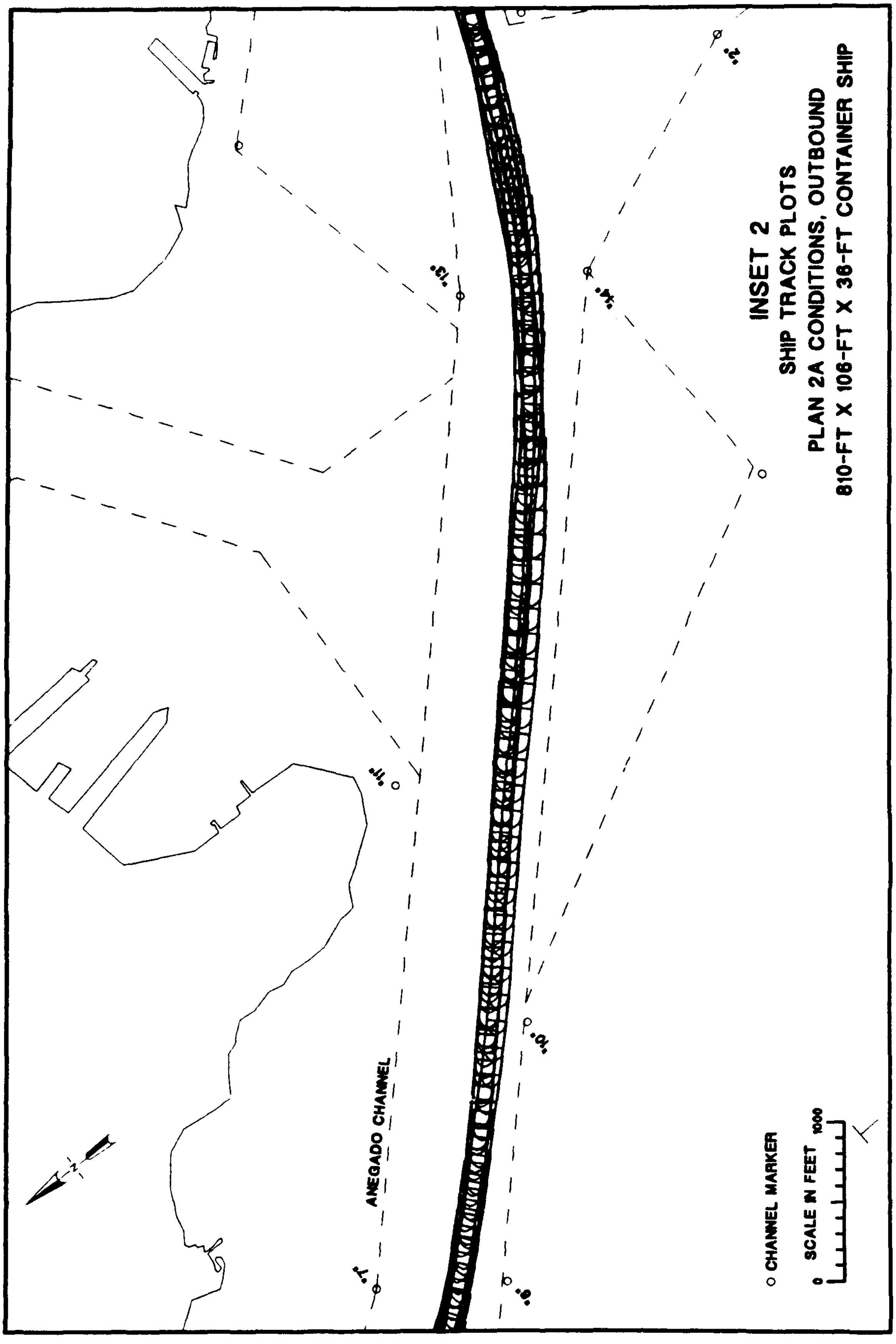

INSET 3
SHIP TRACK PLOTS
PLAN 1A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
PUERTO NUEVO TURNING AREA
GRAVING DOCK CHANNEL
PUERTO NUEVO CHANNEL
ANCHORAGE AREA E
MID-CHANNEL BUOY
"1"
"2"
"3"
"5"
"9"
"10"
N
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000



SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 1
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



INSET 2
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
810-FT X 106-FT X 38-FT CONTAINER SHIP

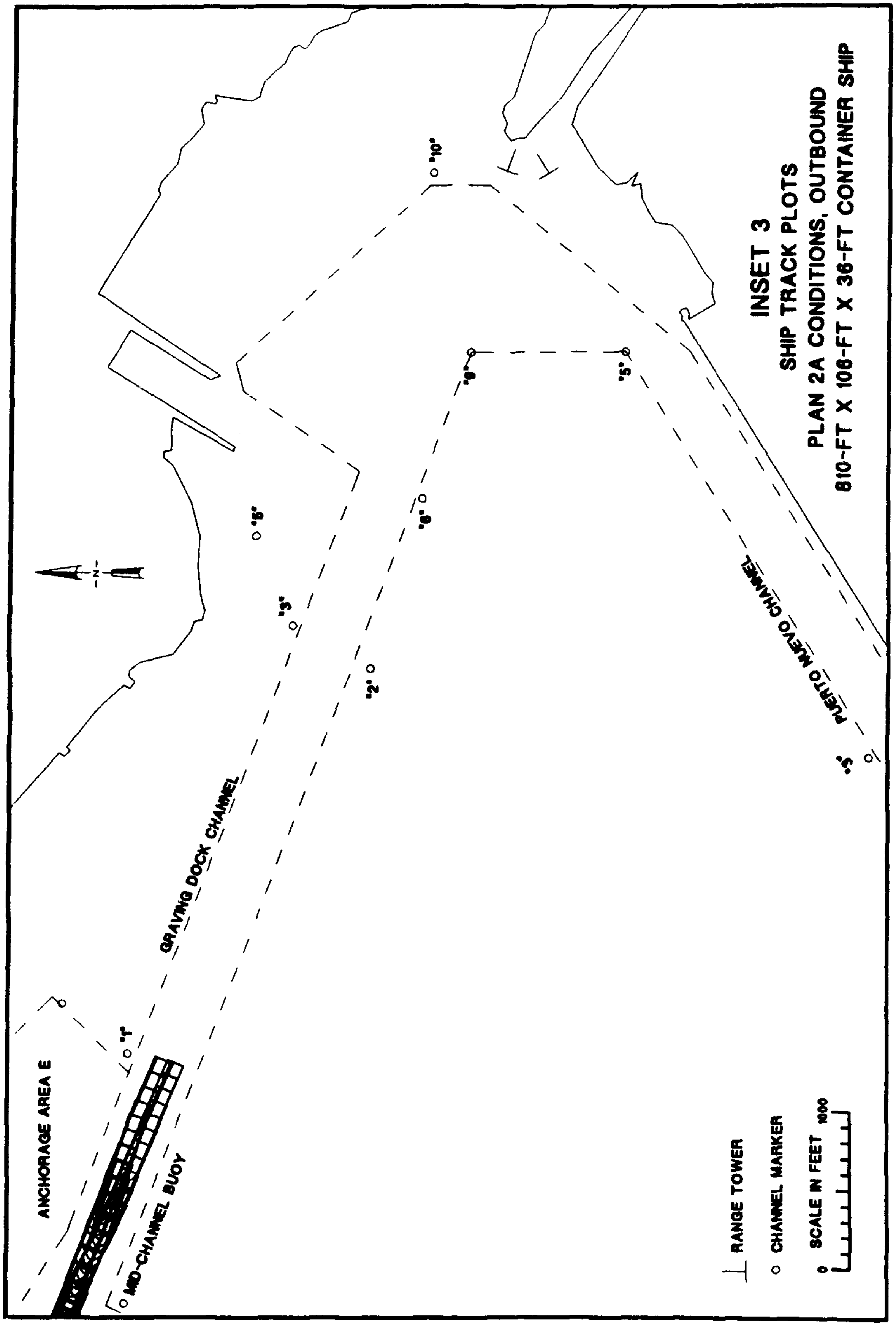
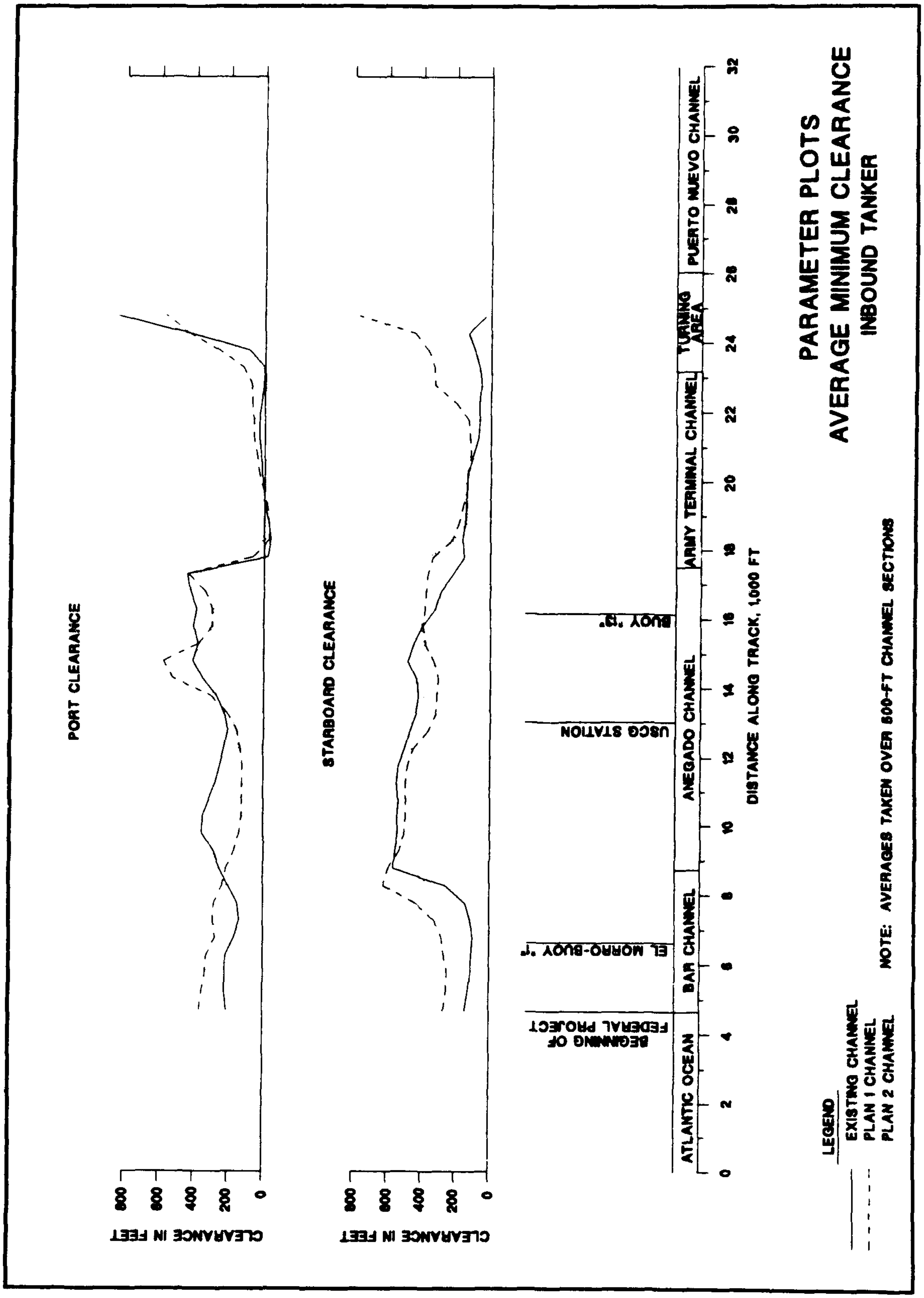
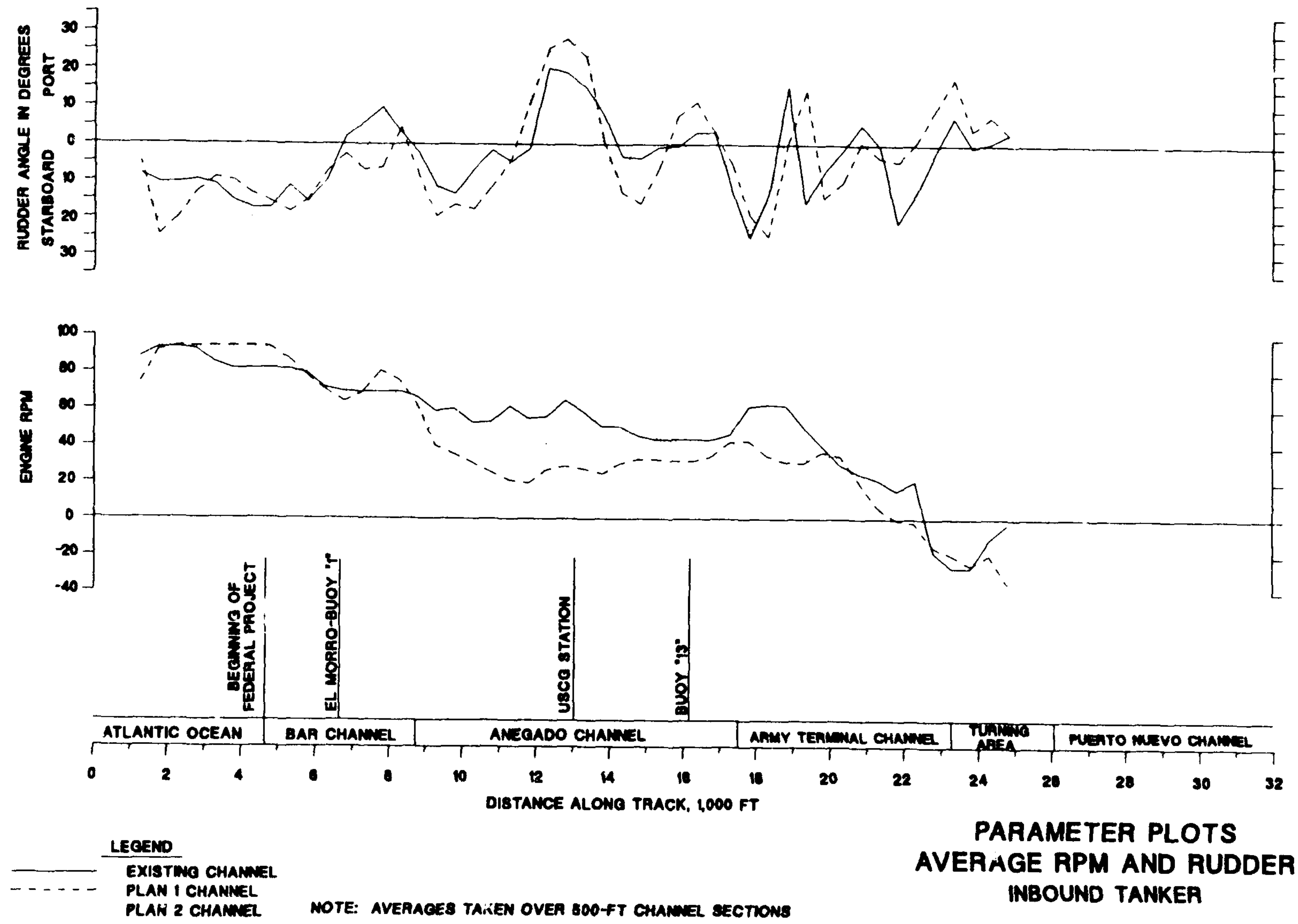

INSET 3
SHIP TRACK PLOTS
PLAN 2A CONDITIONS, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000
ANCHORAGE AREA E
MID-CHANNEL BUOY
GRAVING DOCK CHANNEL
PUERTO NUEVO CHANNEL
"1"
"2"
"3"
"5"
"6"
"8"
"10"
"5"
"5"

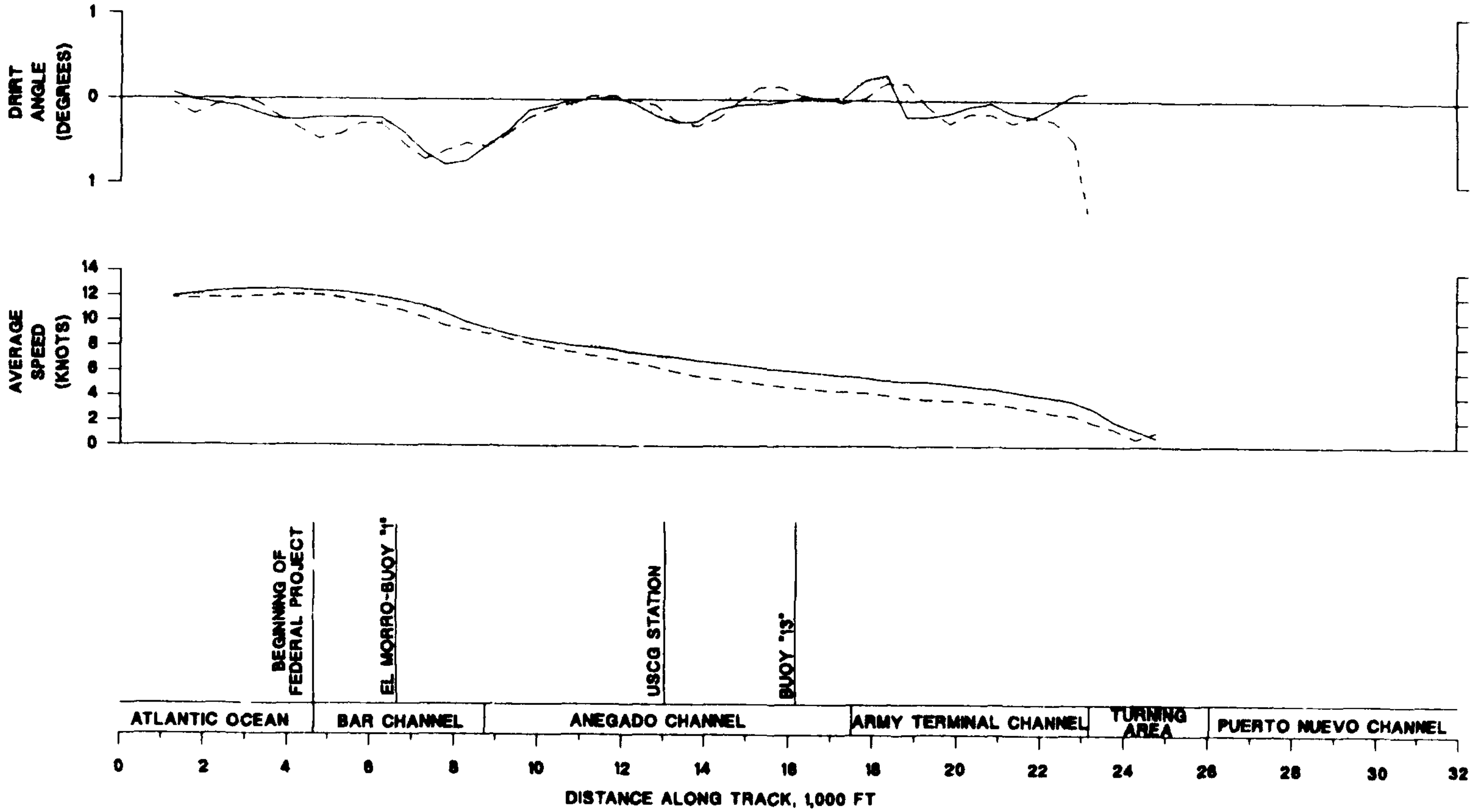
Plate 120

121


PARAMETER PLOTS
AVERAGE MINIMUM CLEARANCE
INBOUND TANKER
PORT CLEARANCE
STARBOARD CLEARANCE
CLEARANCE IN FEET
800
600
400
200
0
CLEARANCE IN FEET
800
600
400
200
0
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
ARMY TERMINAL CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "J"
USCG STATION
BUOY "13"
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DISTANCE ALONG TRACK, 1,000 FT
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS



PARAMETER PLOTS
AVERAGE RPM AND RUDDER
INBOUND TANKER

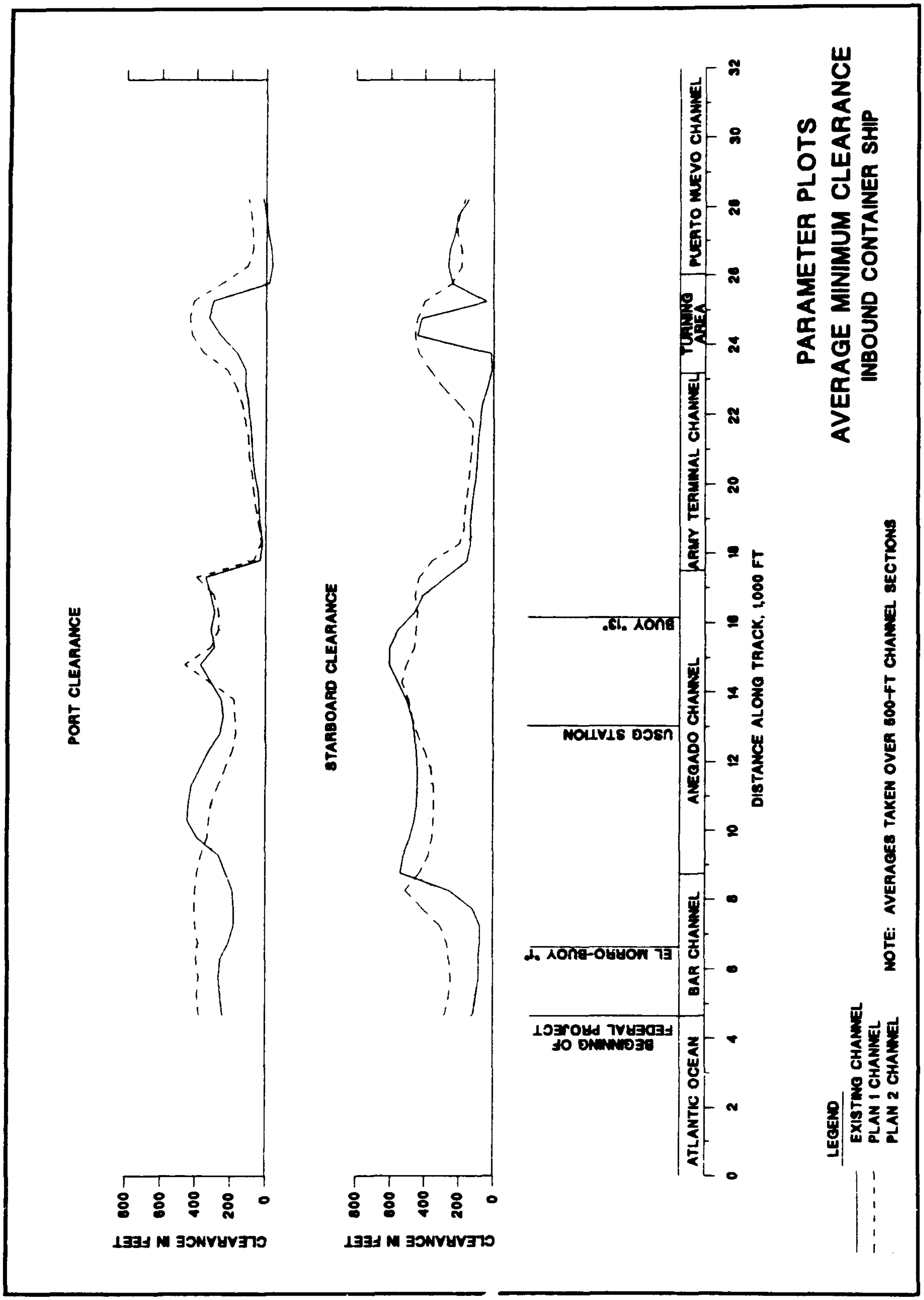


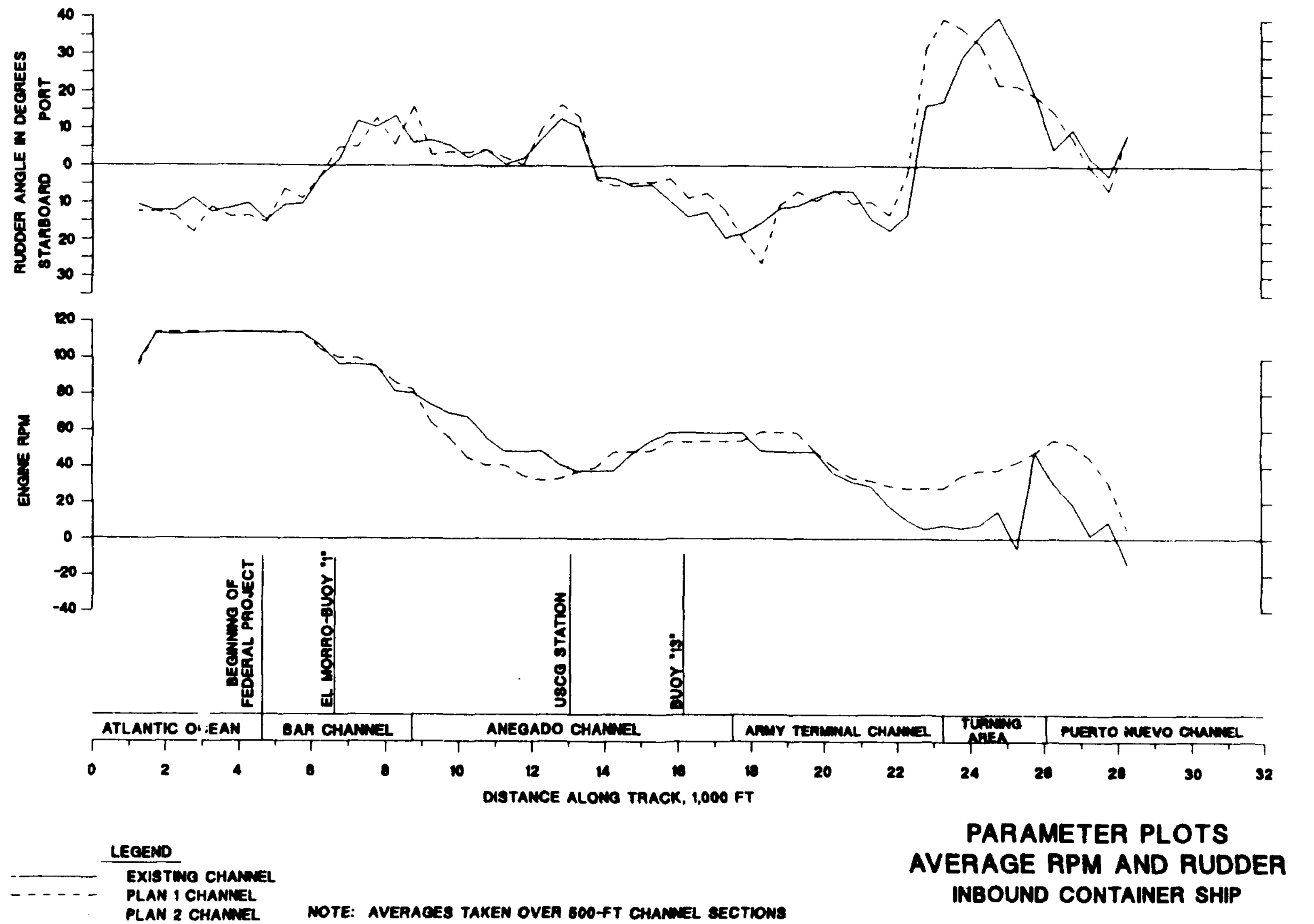
LEGEND

EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

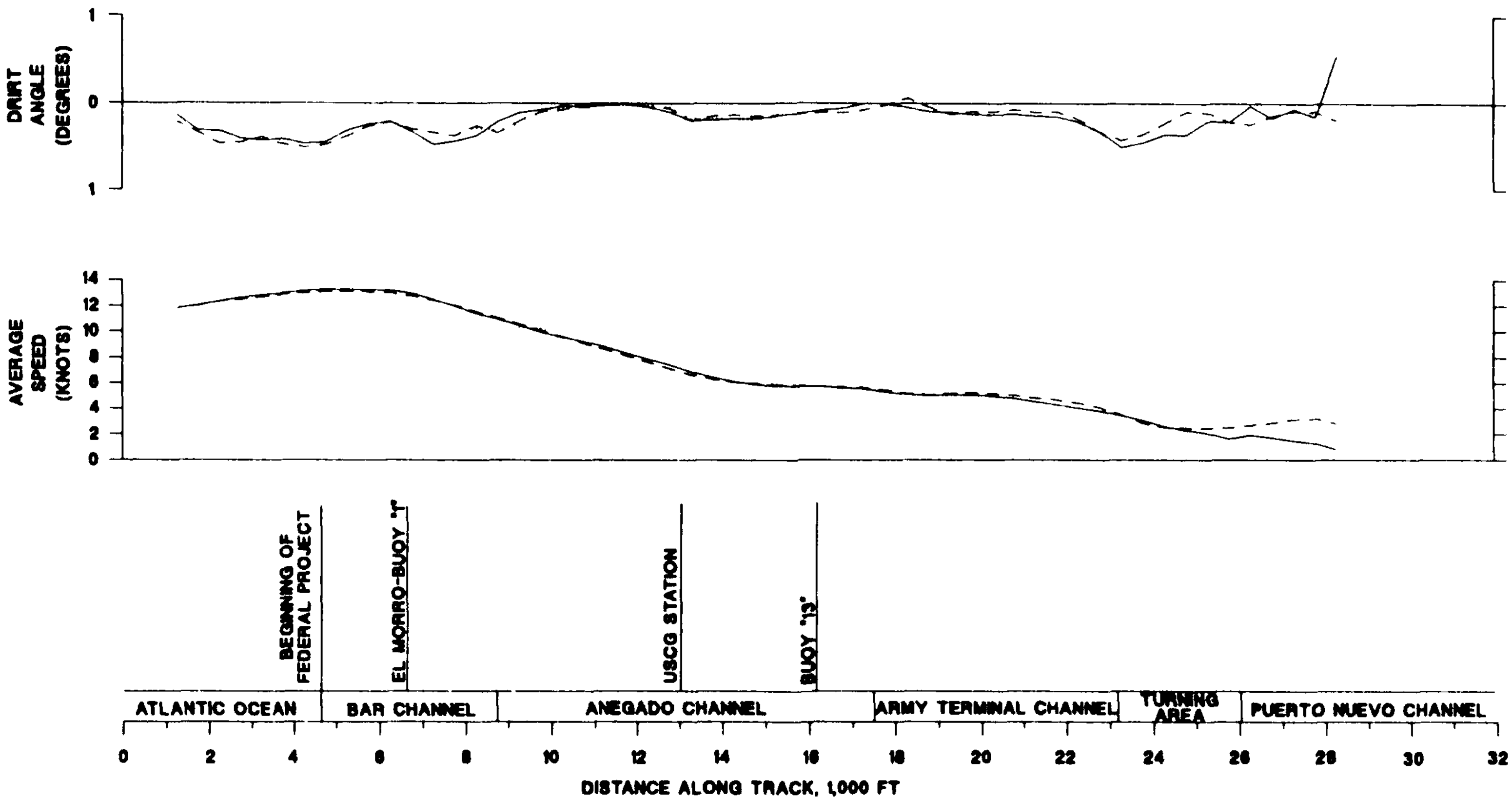
PARAMETER PLOTS
AVERAGE SPEED AND DRIFT ANGLE
INBOUND TANKER


PARAMETER PLOTS
AVERAGE MINIMUM CLEARANCE
INBOUND CONTAINER SHIP
PORT CLEARANCE
STARBOARD CLEARANCE
CLEARANCE IN FEET
800
600
400
200
0
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
ARMY TERMINAL CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "1"
USCG STATION
BUOY "13"
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
DISTANCE ALONG TRACK, 1,000 FT
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS



NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

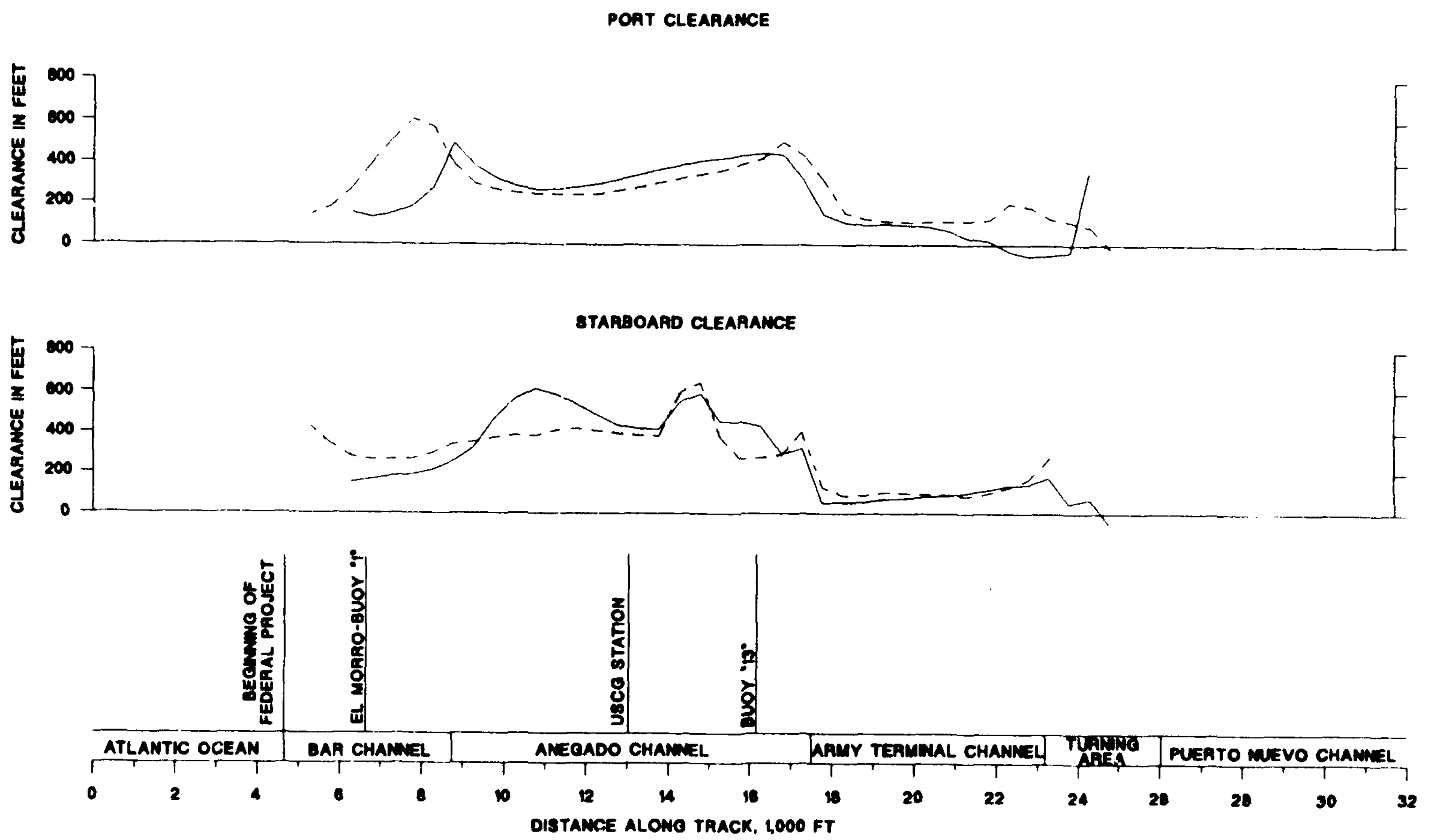
PARAMETER PLOTS
AVERAGE RPM AND RUDDER
INBOUND CONTAINER SHIP



PARAMETER PLOTS
AVERAGE SPEED AND DRIFT ANGLE
INBOUND CONTAINER SHIP

LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS



LEGEND

EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

PARAMETER PLOTS
AVERAGE MINIMUM CLEARANCE
OUTBOUND TANKER

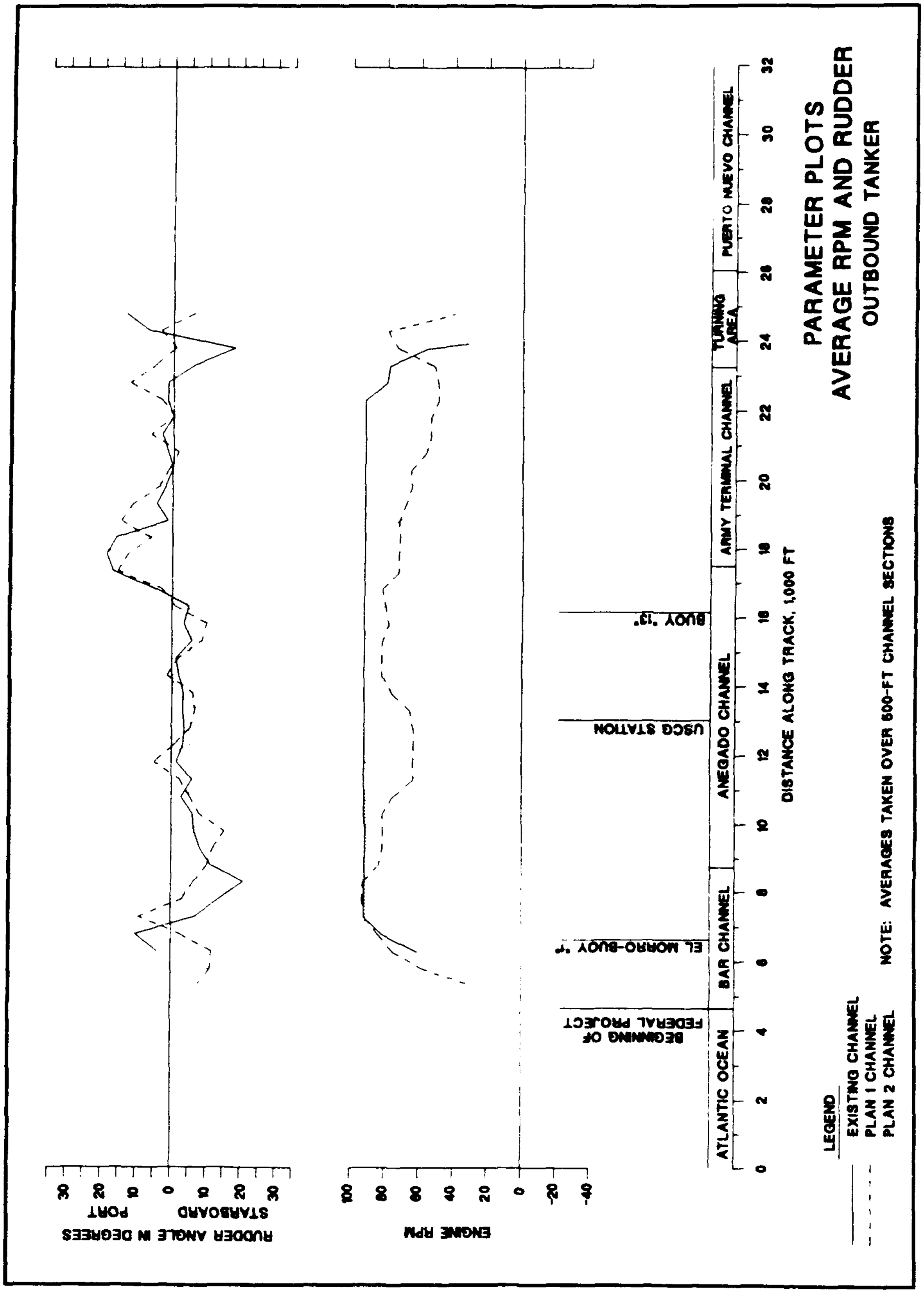
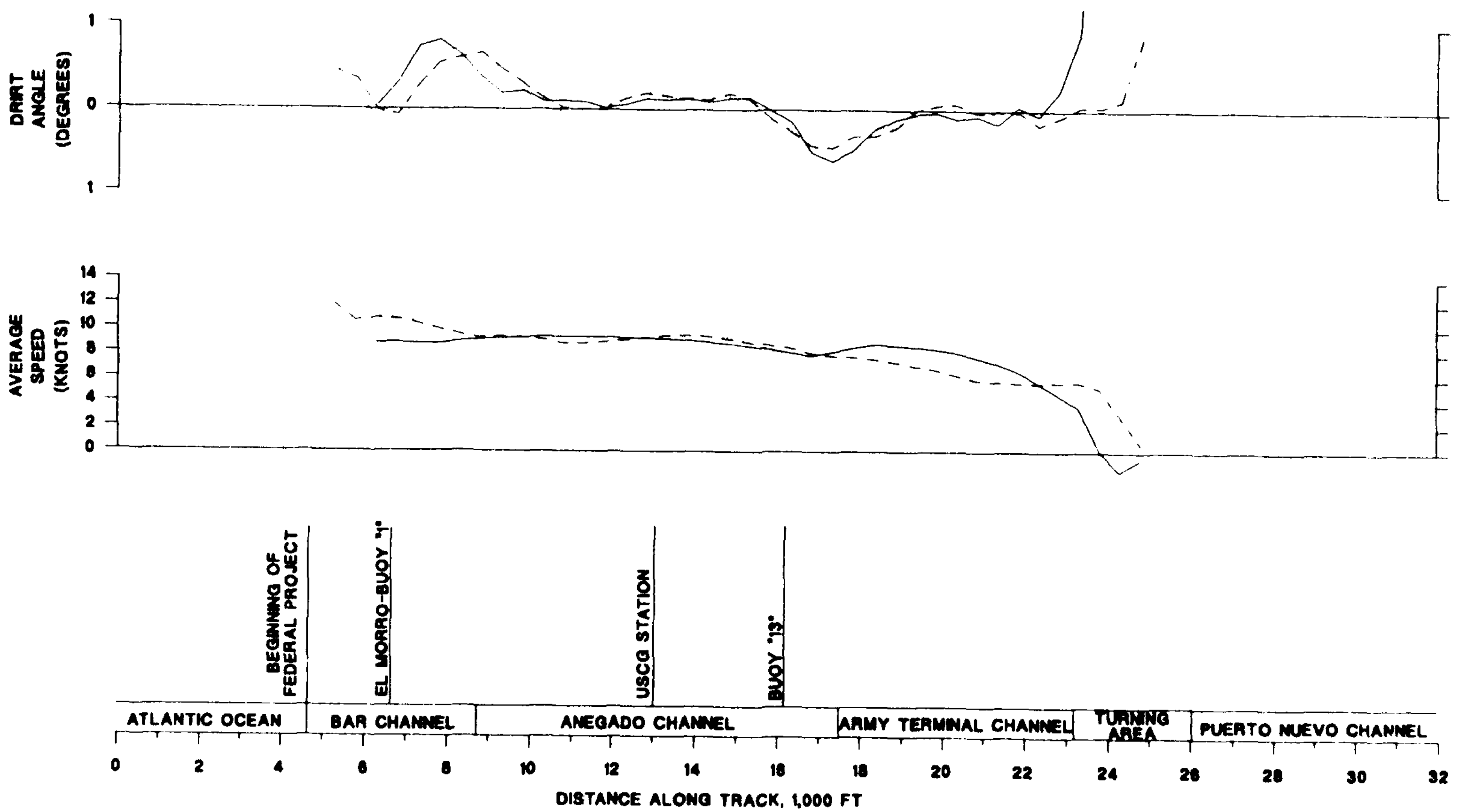

PARAMETER PLOTS
AVERAGE RPM AND RUDDER
OUTBOUND TANKER
RUDDER ANGLE IN DEGREES
PORT
STARBOARD
ENGINE RPM
DISTANCE ALONG TRACK, 1,000 FT
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
ARMY TERMINAL CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "I"
USCG STATION
BUOY "13"
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

Plate 128



LEGEND

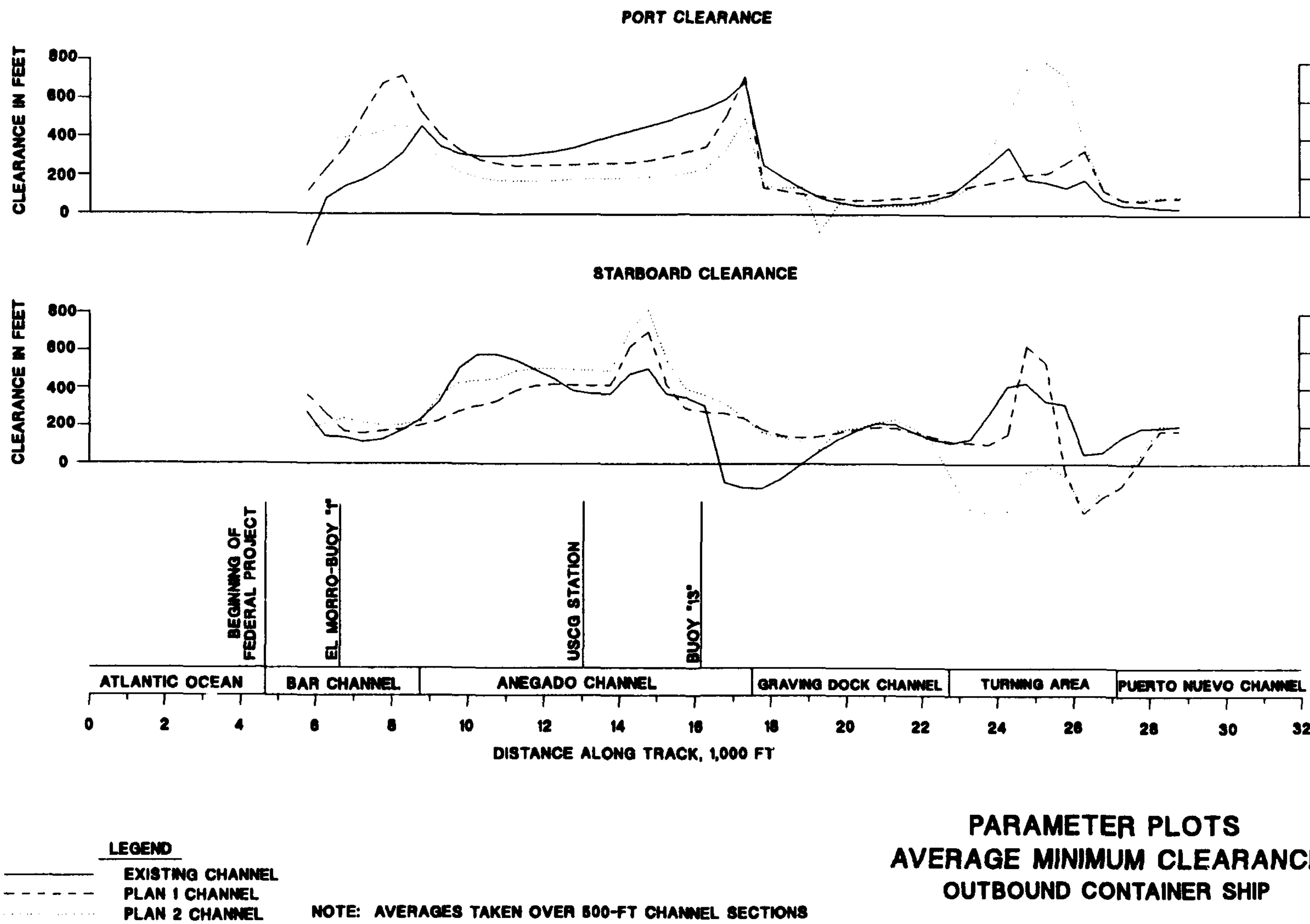
EXISTING CHANNEL

PLAN 1 CHANNEL

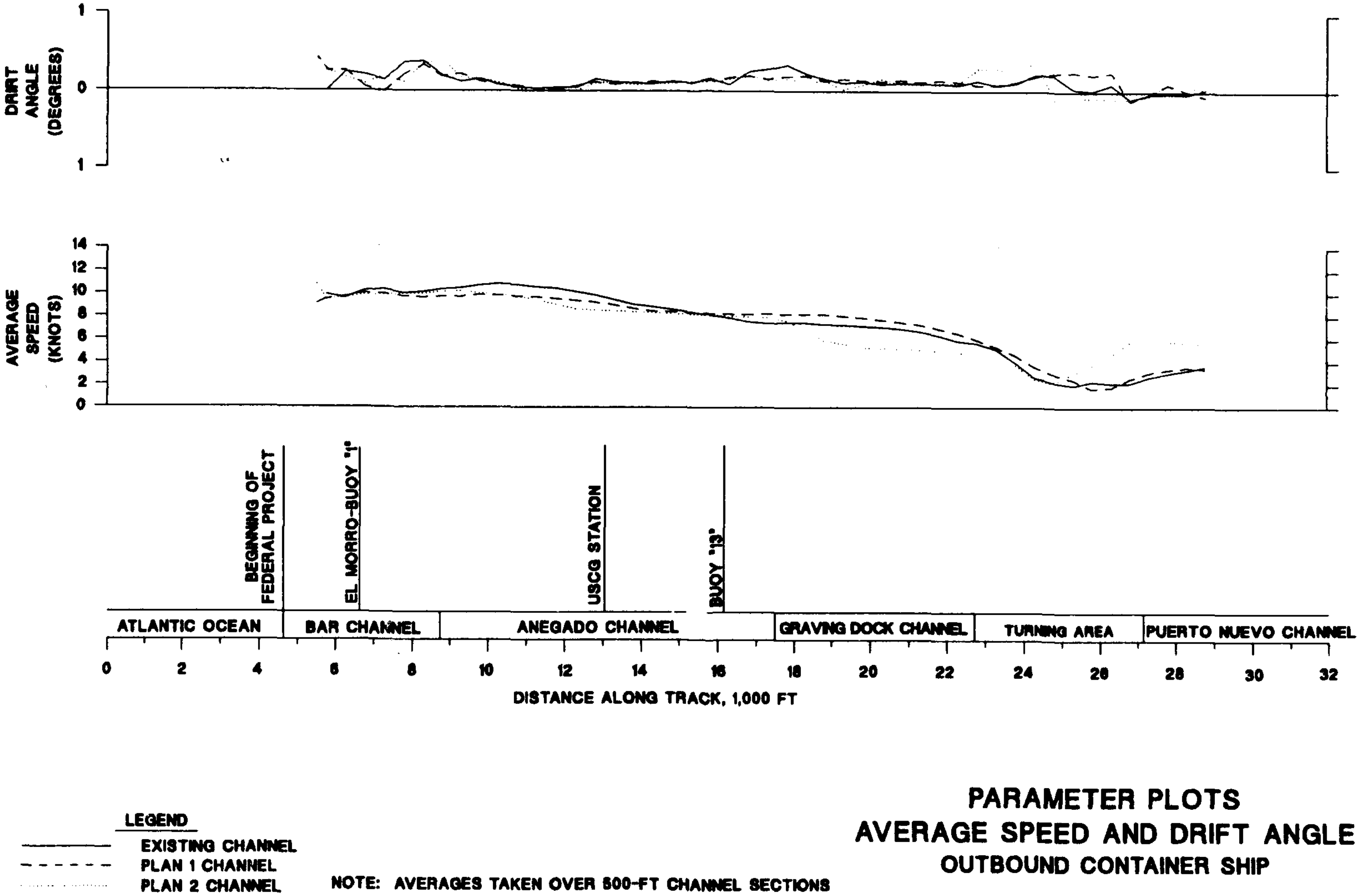
PLAN 2 CHANNEL

NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

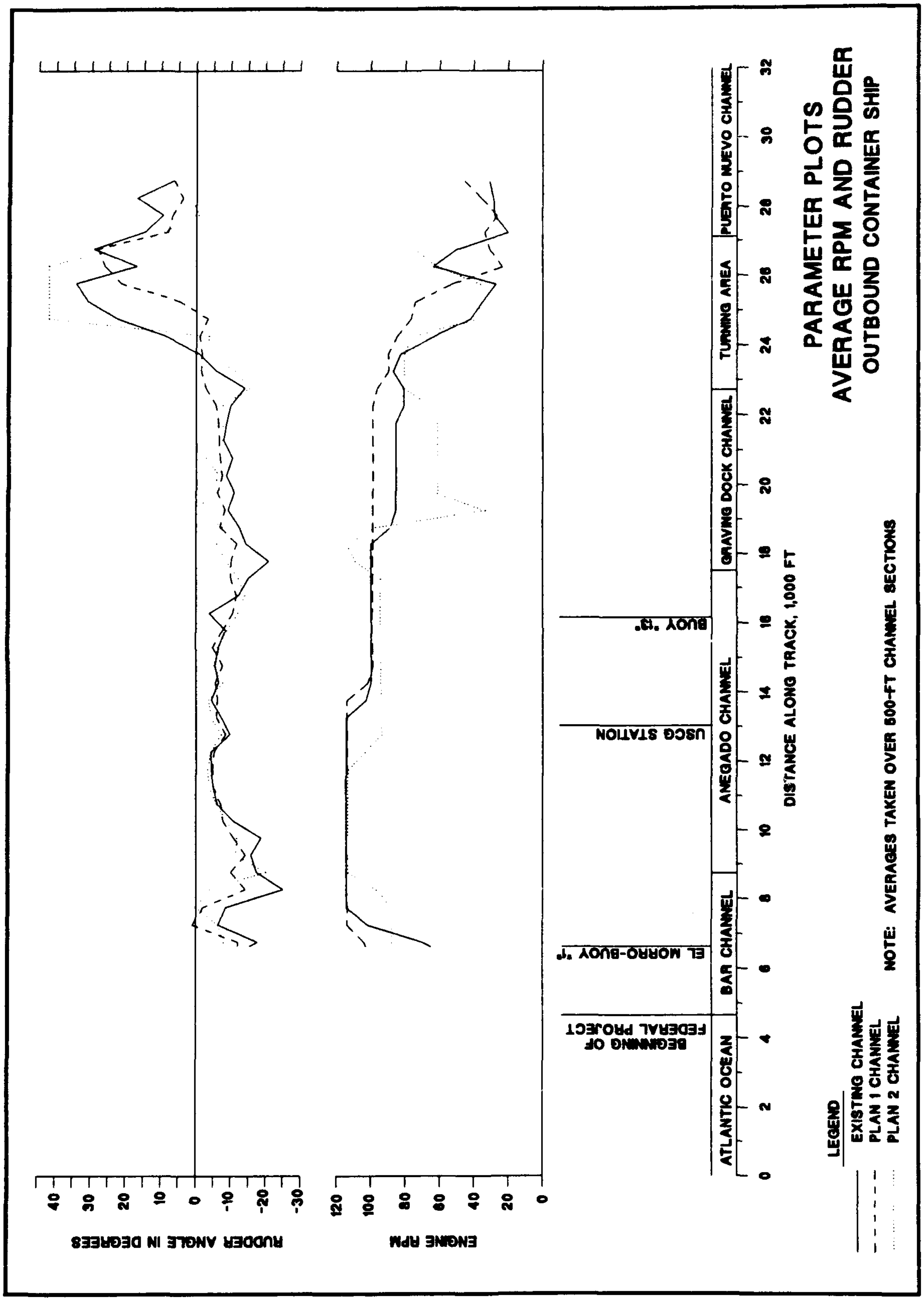
PARAMETER PLOTS
AVERAGE SPEED AND DRIFT ANGLE
OUTBOUND TANKER

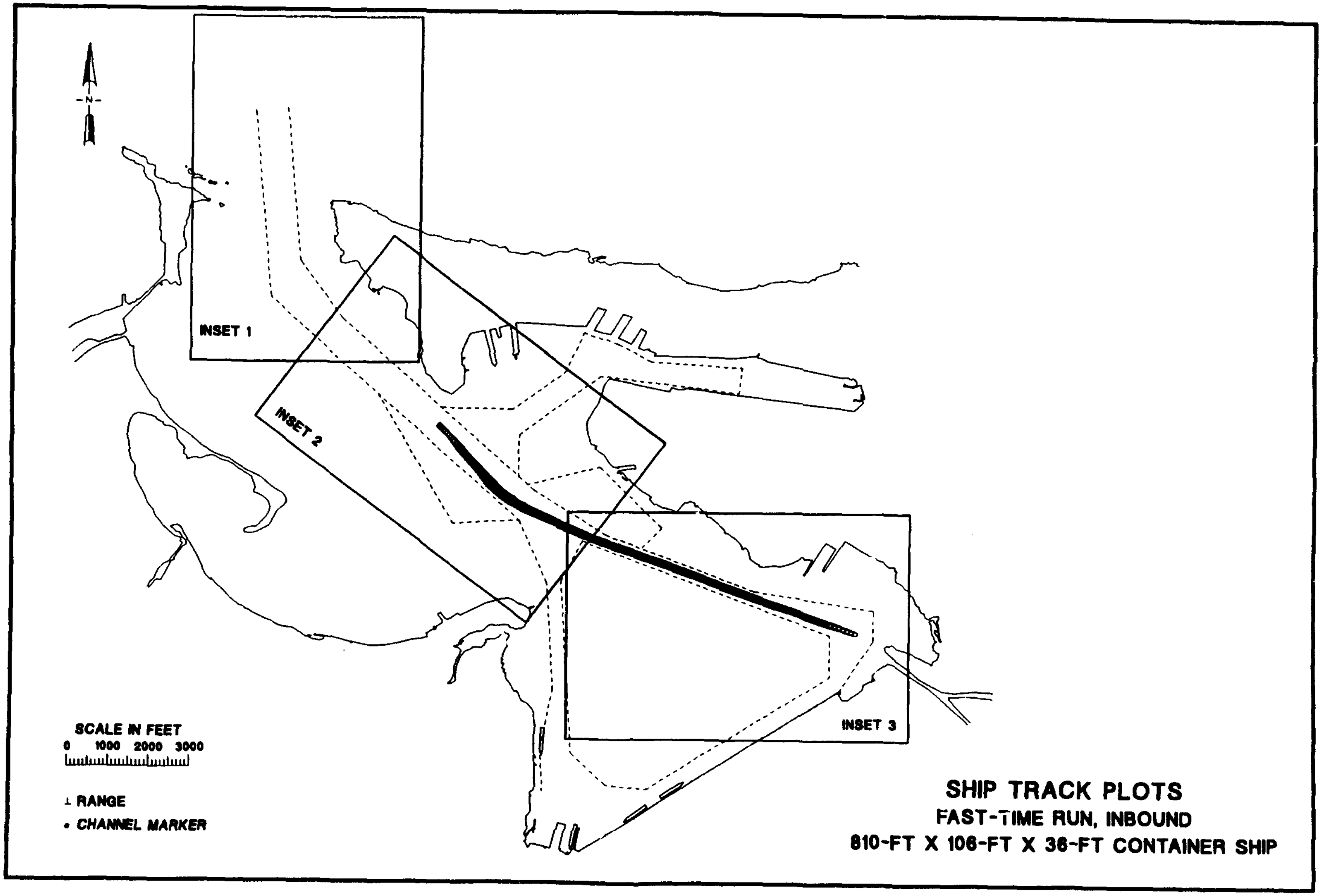


PARAMETER PLOTS
AVERAGE MINIMUM CLEARANCE
OUTBOUND CONTAINER SHIP

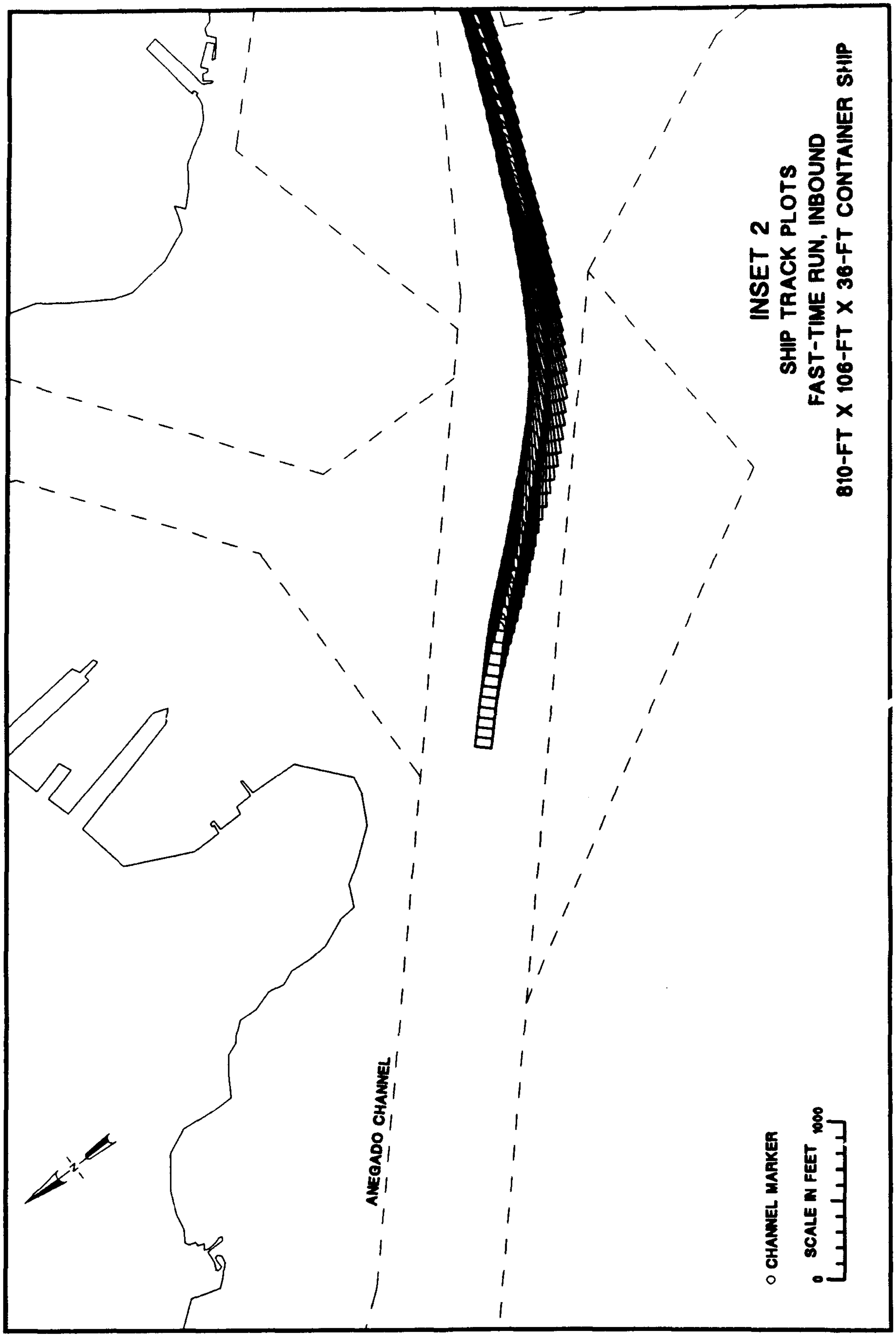


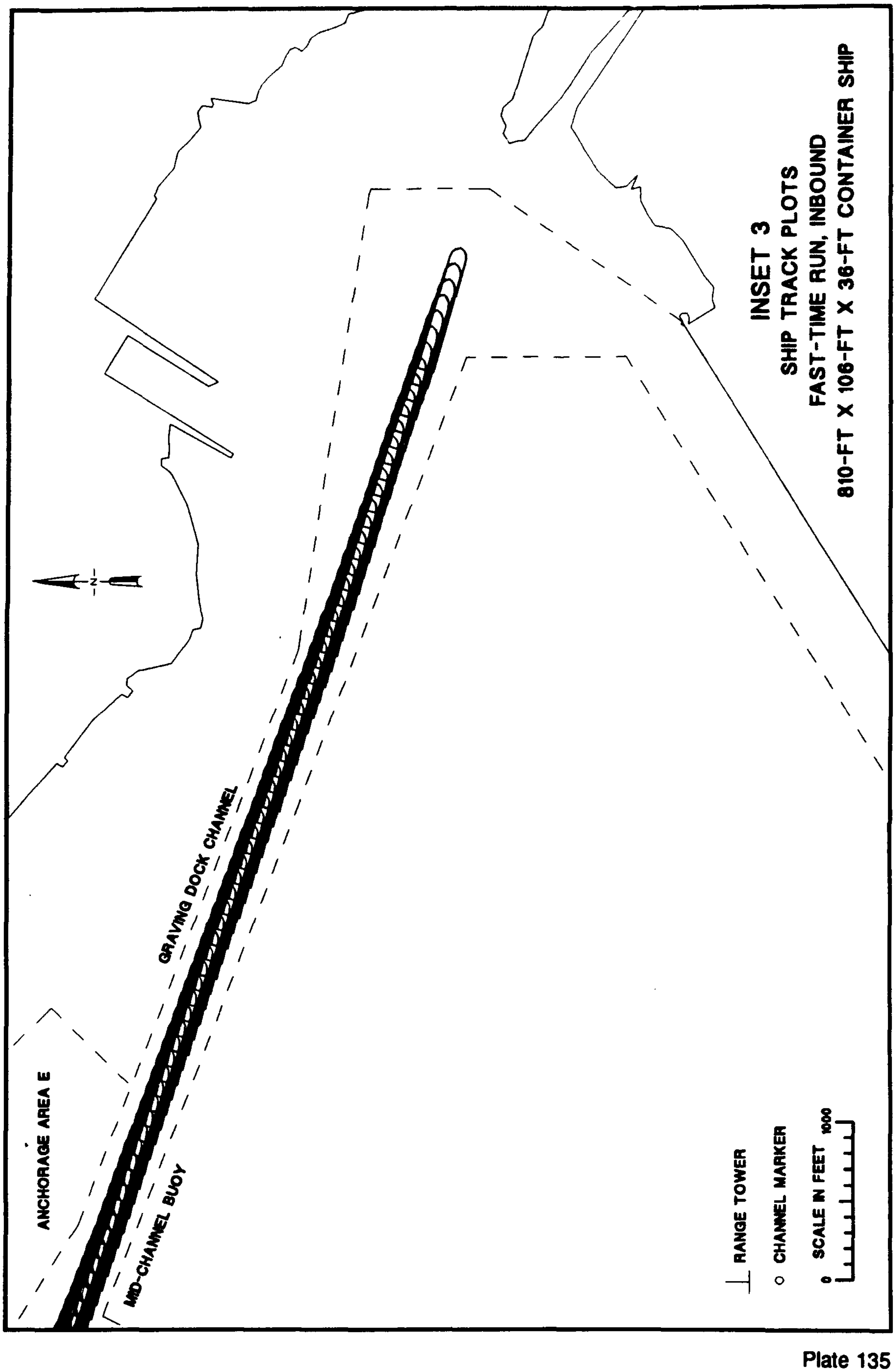
PARAMETER PLOTS
AVERAGE SPEED AND DRIFT ANGLE
OUTBOUND CONTAINER SHIP


PARAMETER PLOTS
AVERAGE RPM AND RUDDER
OUTBOUND CONTAINER SHIP
RUDDER ANGLE IN DEGREES
ENGINE RPM
DISTANCE ALONG TRACK, 1,000 FT
ATLANTIC OCEAN
BAR CHANNEL
ANEGADO CHANNEL
GRAVING DOCK CHANNEL
TURNING AREA
PUERTO NUEVO CHANNEL
BEGINNING OF FEDERAL PROJECT
EL MORRO-BUOY "1"
USCG STATION
BUOY "13"
LEGEND
EXISTING CHANNEL
PLAN 1 CHANNEL
PLAN 2 CHANNEL
NOTE: AVERAGES TAKEN OVER 500-FT CHANNEL SECTIONS

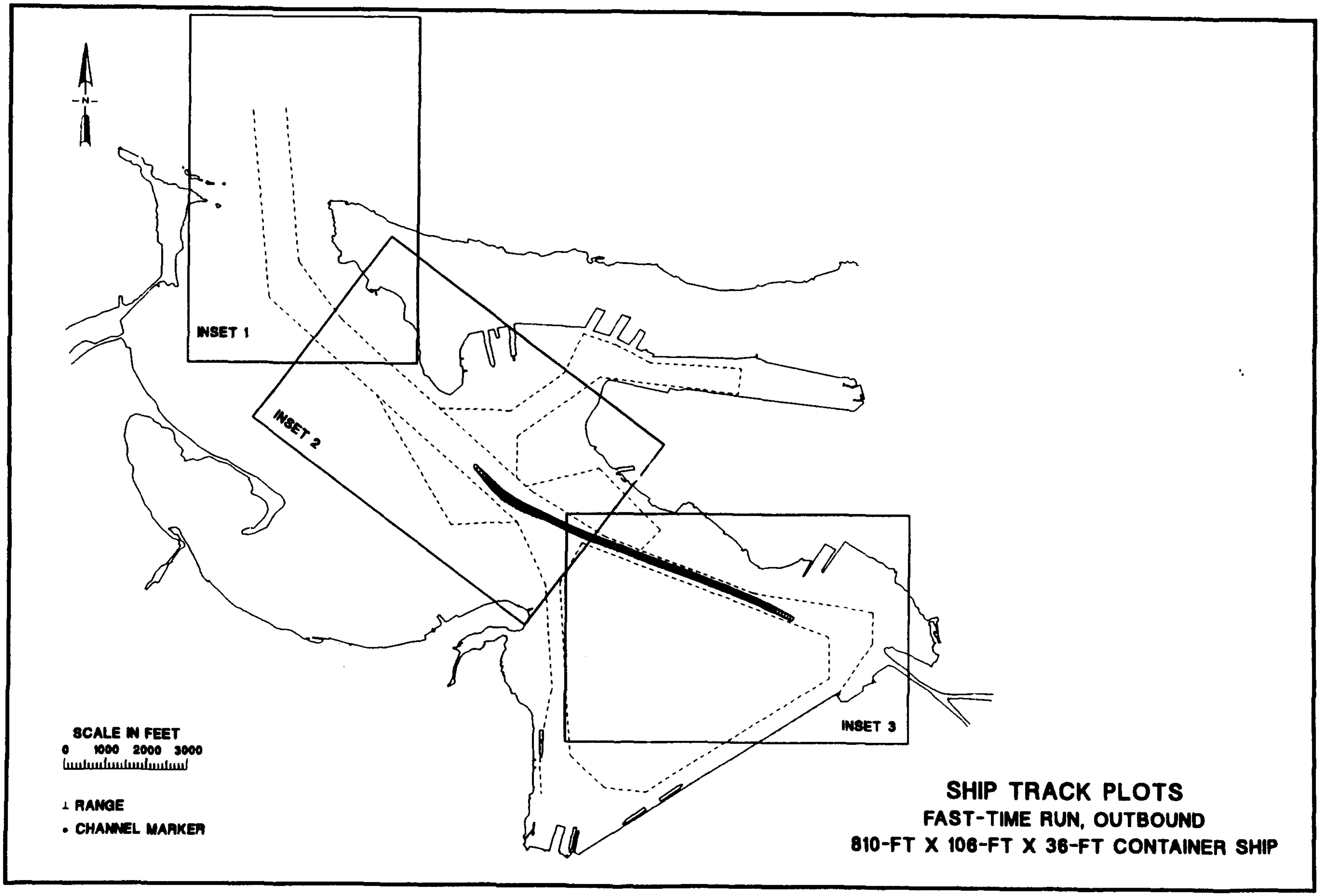


SHIP TRACK PLOTS
FAST-TIME RUN, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP


INSET 2
SHIP TRACK PLOTS
FAST-TIME RUN, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANEGADO CHANNEL
N
CHANNEL MARKER
SCALE IN FEET
0
1000



INSET 3
SHIP TRACK PLOTS
FAST-TIME RUN, INBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP



SHIP TRACK PLOTS
FAST-TIME RUN, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP

Plate 136

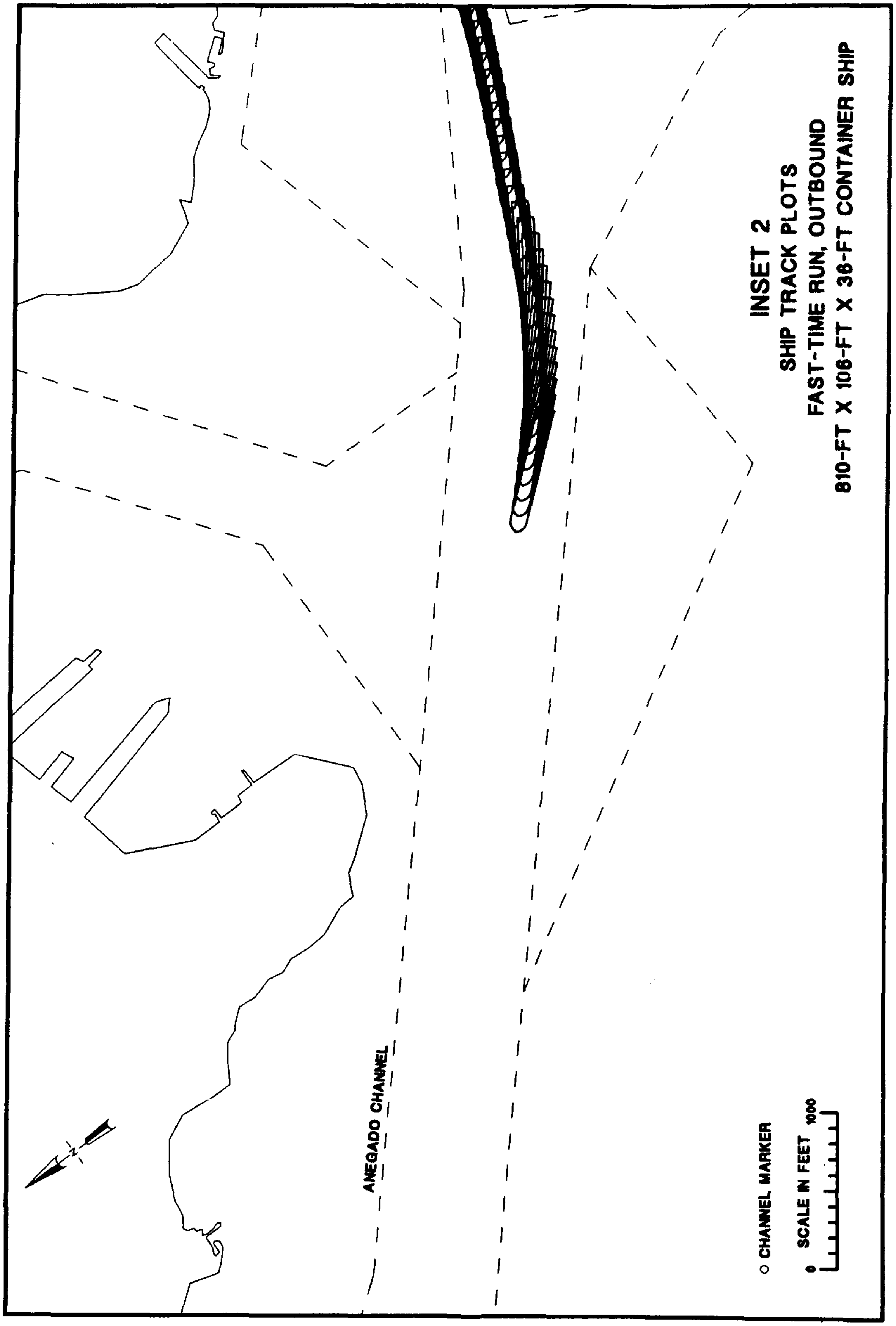
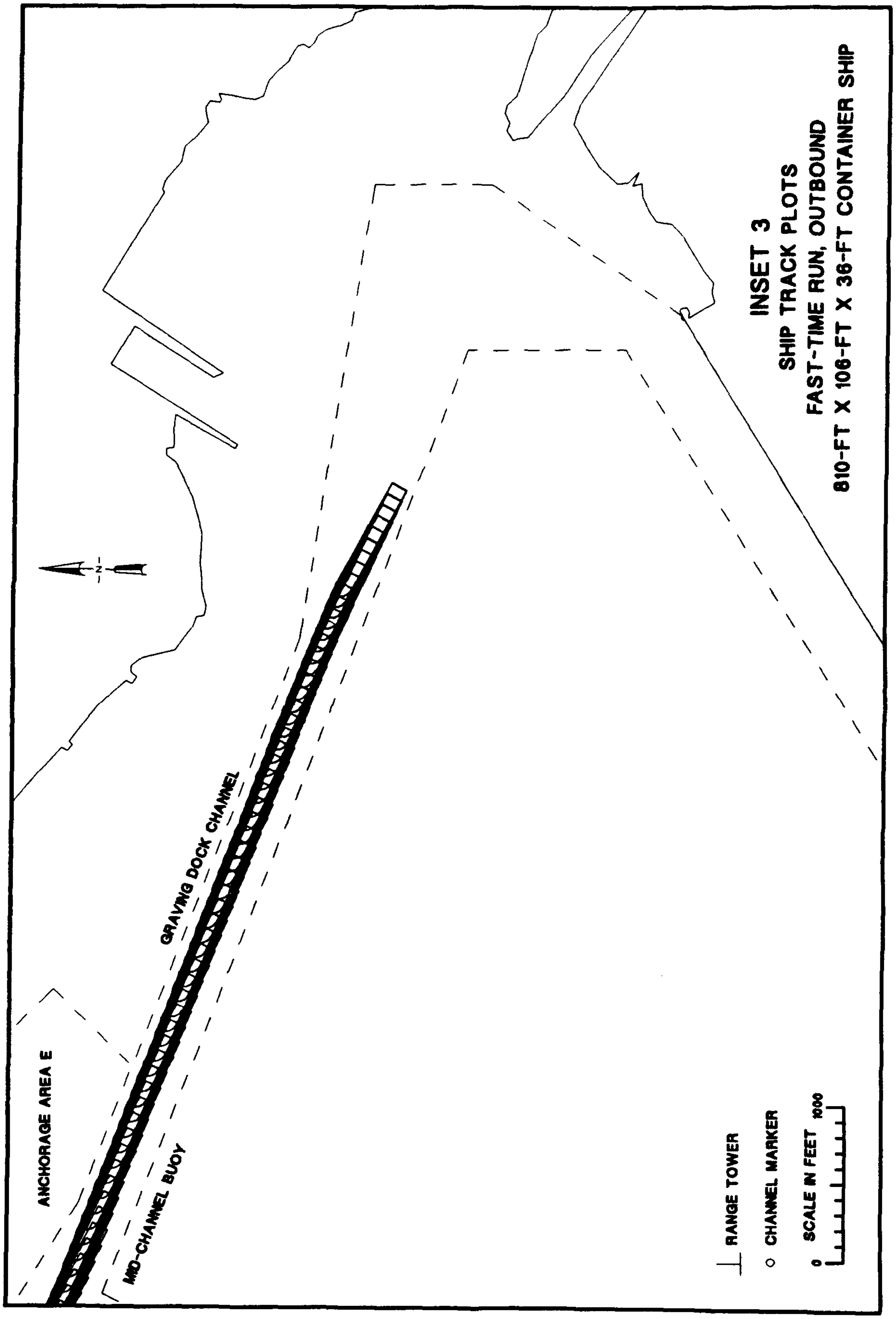
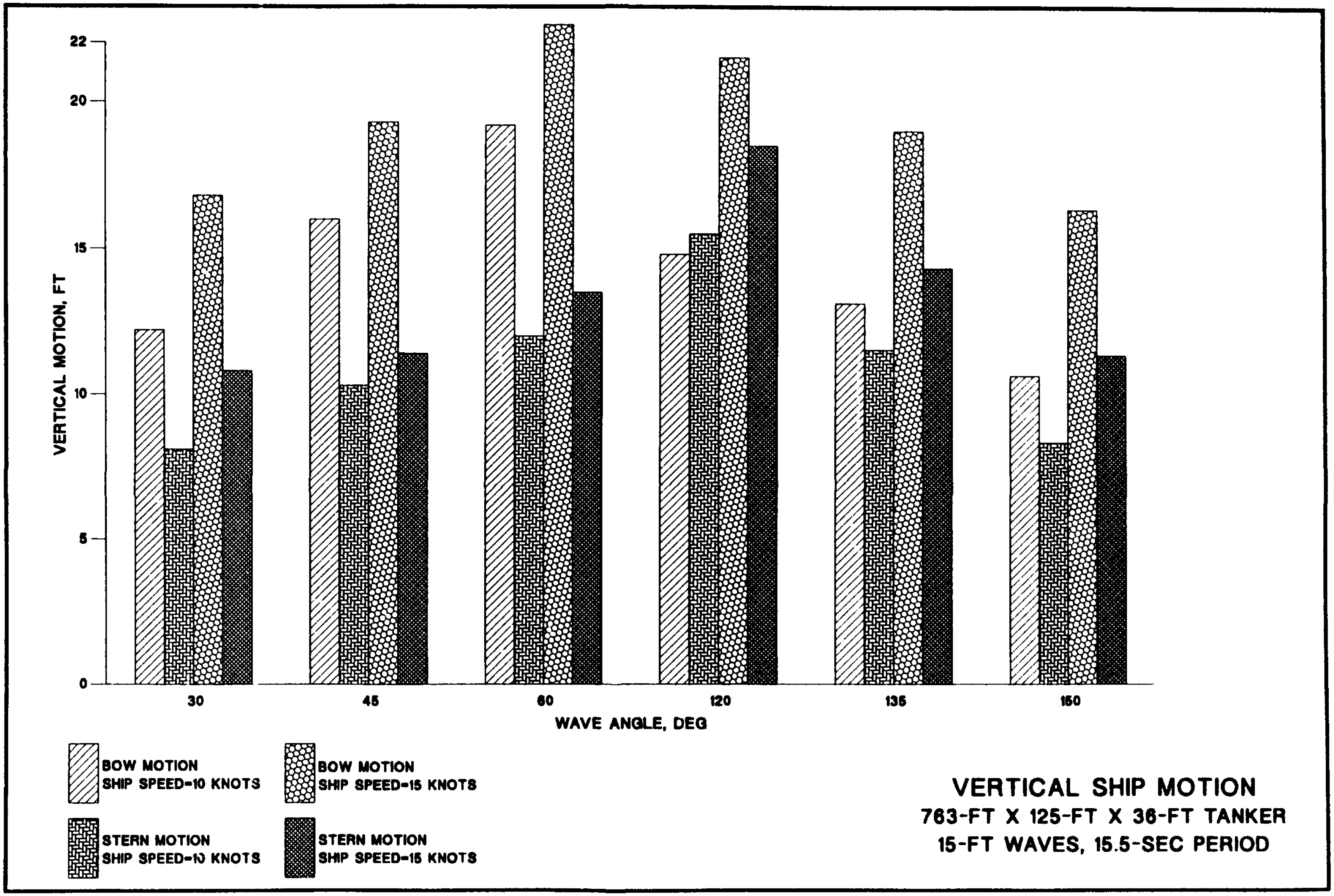
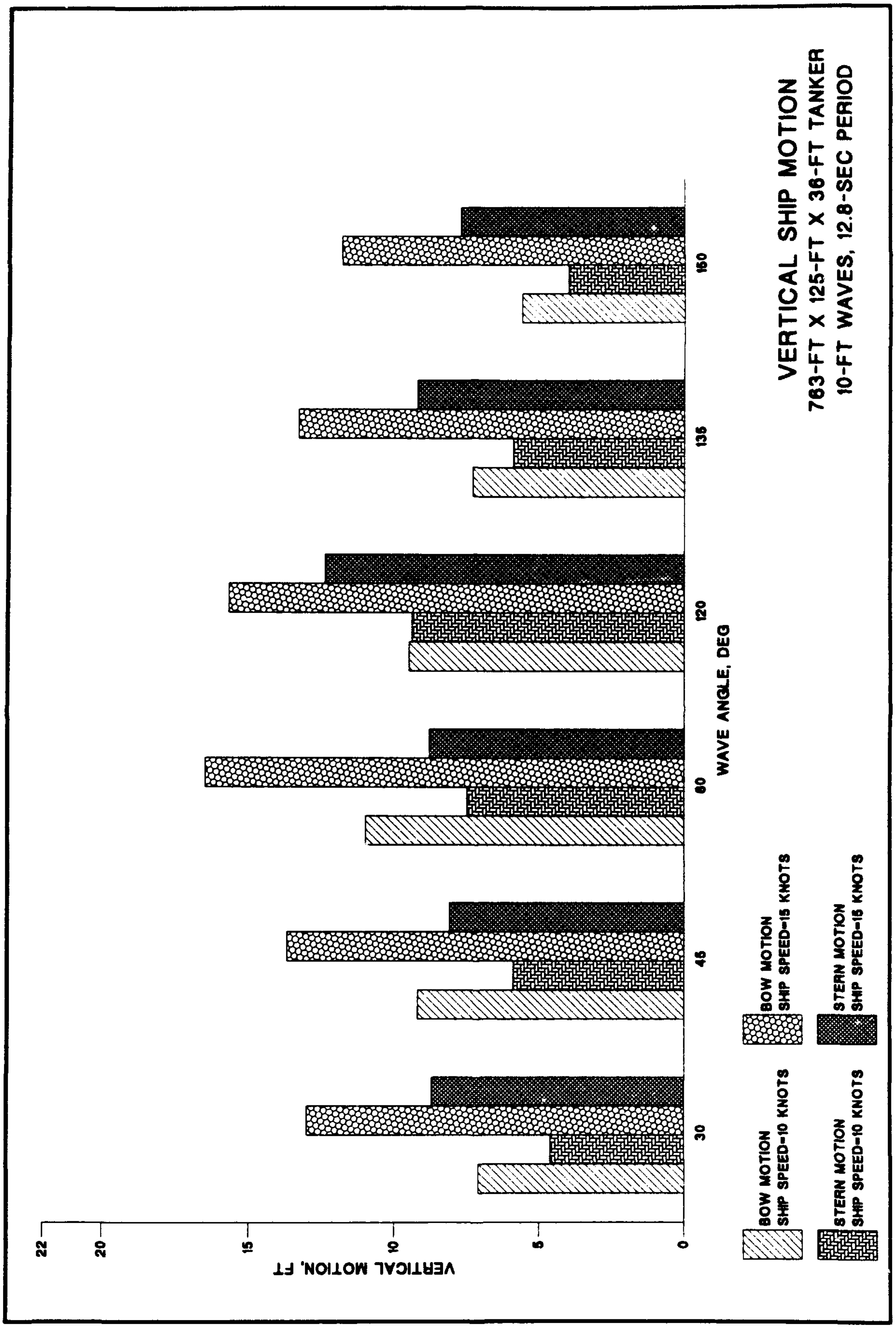

INSET 2
SHIP TRACK PLOTS
FAST-TIME RUN, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
ANEGADO CHANNEL
N
○ CHANNEL MARKER
SCALE IN FEET
0
1000

Plate 137

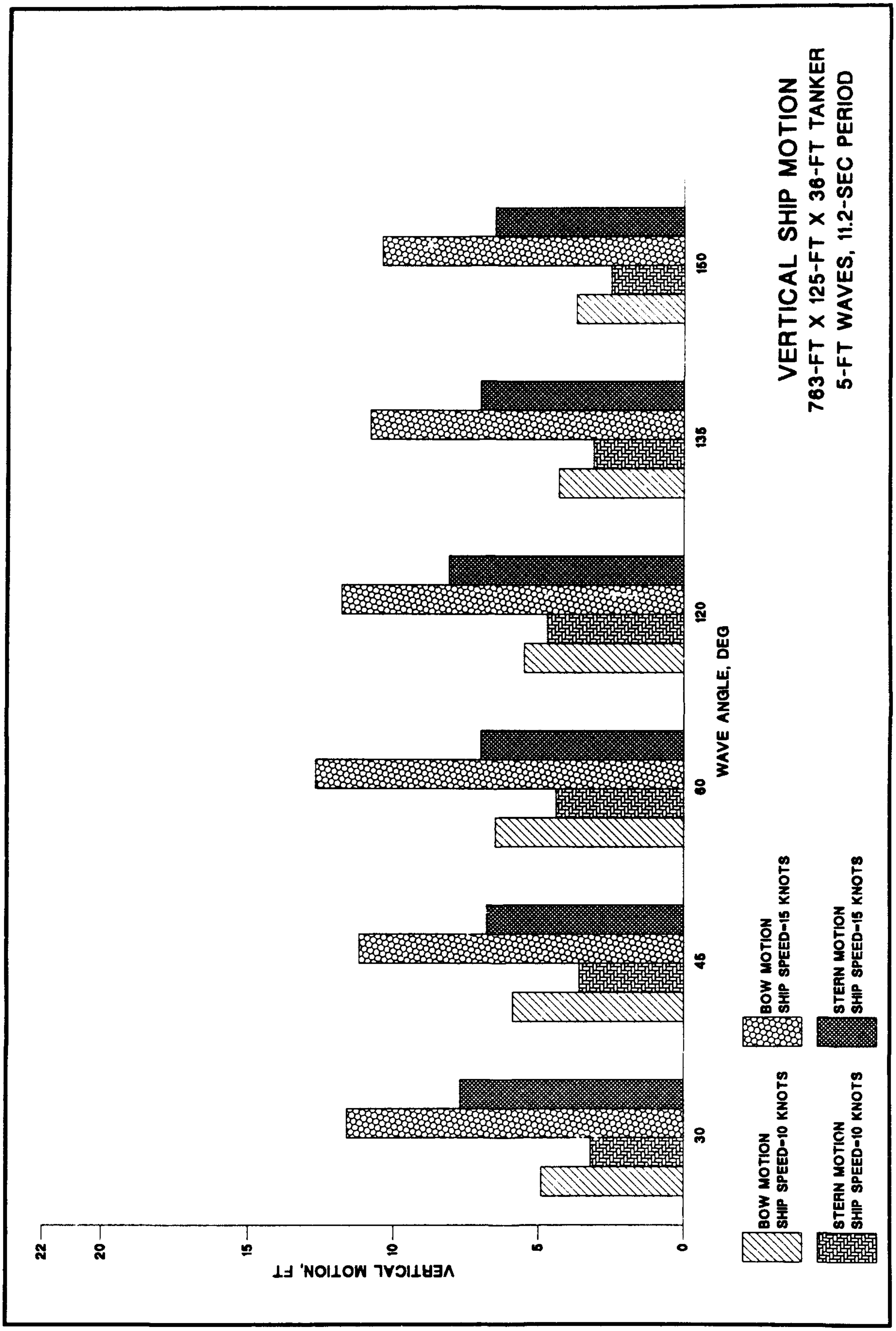

INSET 3
SHIP TRACK PLOTS
FAST-TIME RUN, OUTBOUND
810-FT X 106-FT X 36-FT CONTAINER SHIP
GRAVING DOCK CHANNEL
ANCHORAGE AREA E
MID-CHANNEL BUOY
RANGE TOWER
CHANNEL MARKER
SCALE IN FEET
0
1000
N


VERTICAL MOTION, FT
22
20
15
10
5
0
30
45
60
120
135
150
WAVE ANGLE, DEG
BOW MOTION
SHIP SPEED=10 KNOTS
BOW MOTION
SHIP SPEED=15 KNOTS
STERN MOTION
SHIP SPEED=10 KNOTS
STERN MOTION
SHIP SPEED=15 KNOTS
VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
15-FT WAVES, 15.5-SEC PERIOD



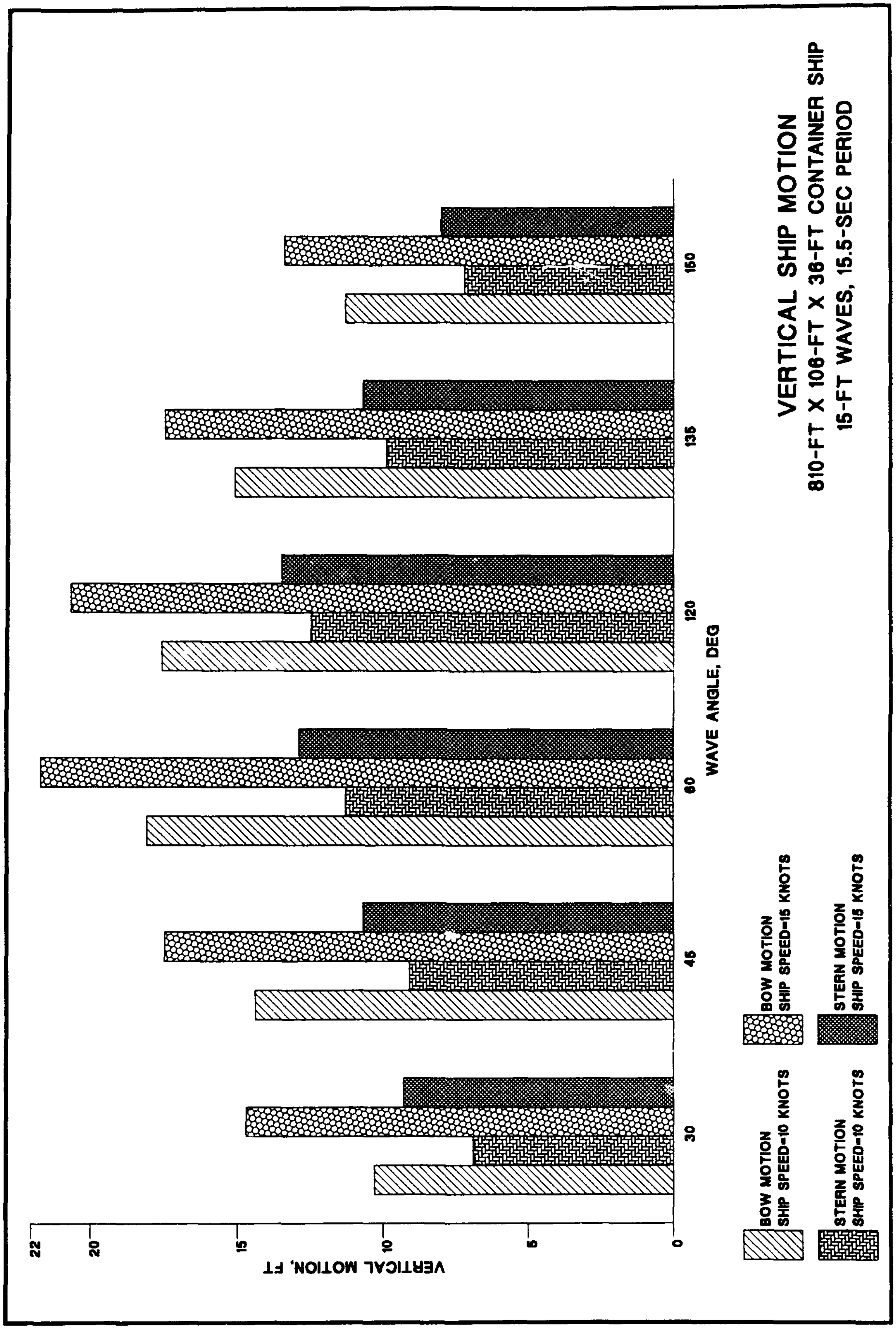
VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
10-FT WAVES, 12.8-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
90
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

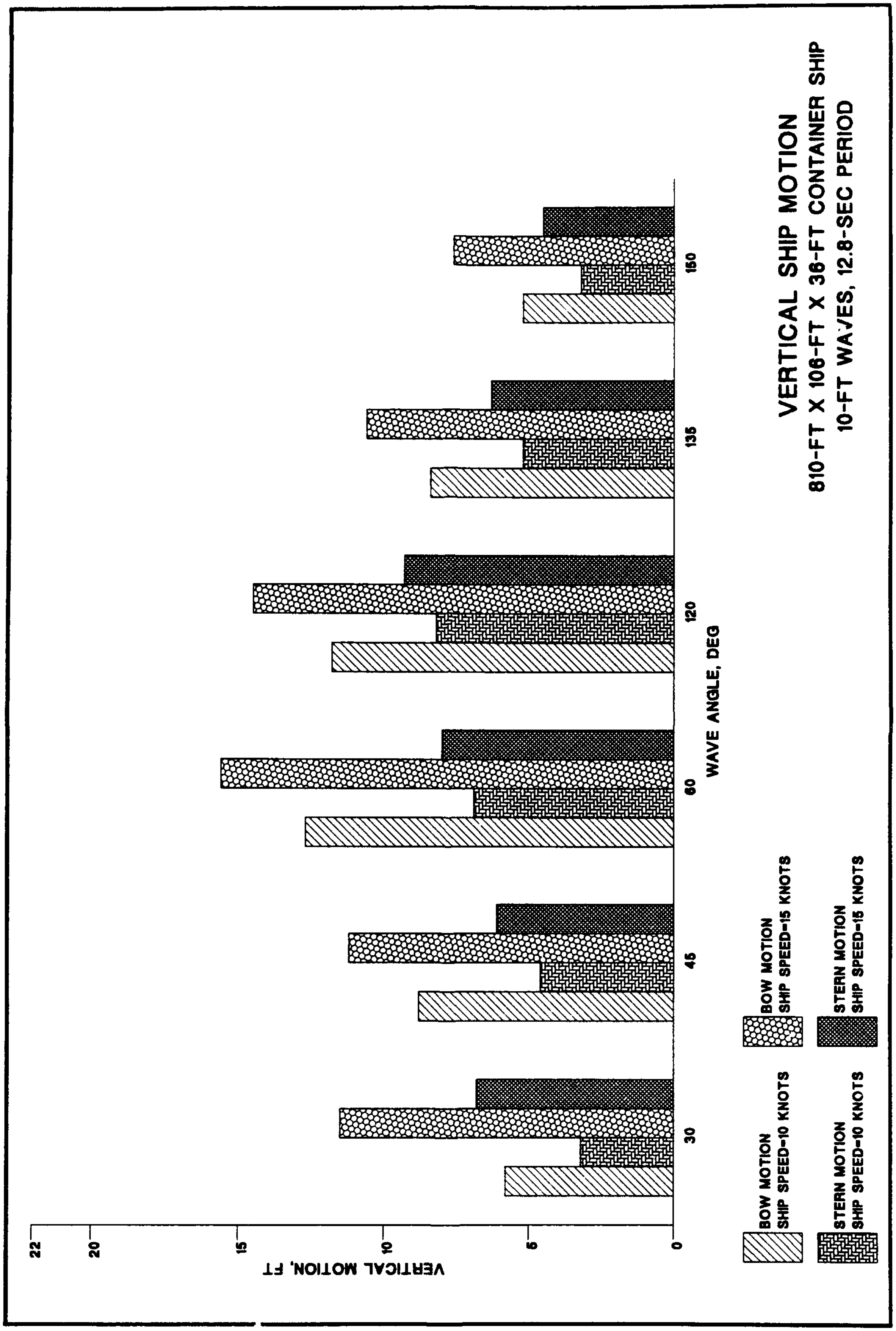
Plate 140



VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
5-FT WAVES, 11.2-SEC PERIOD
VERTICAL MOTION, FT
WAVE ANGLE, DEG
0
5
10
15
20
22
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

Plate 141


VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
15-FT WAVES, 15.5-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED=10 KNOTS
BOW MOTION
SHIP SPEED=15 KNOTS
STERN MOTION
SHIP SPEED=10 KNOTS
STERN MOTION
SHIP SPEED=15 KNOTS


VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
10-FT WAVES, 12.8-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

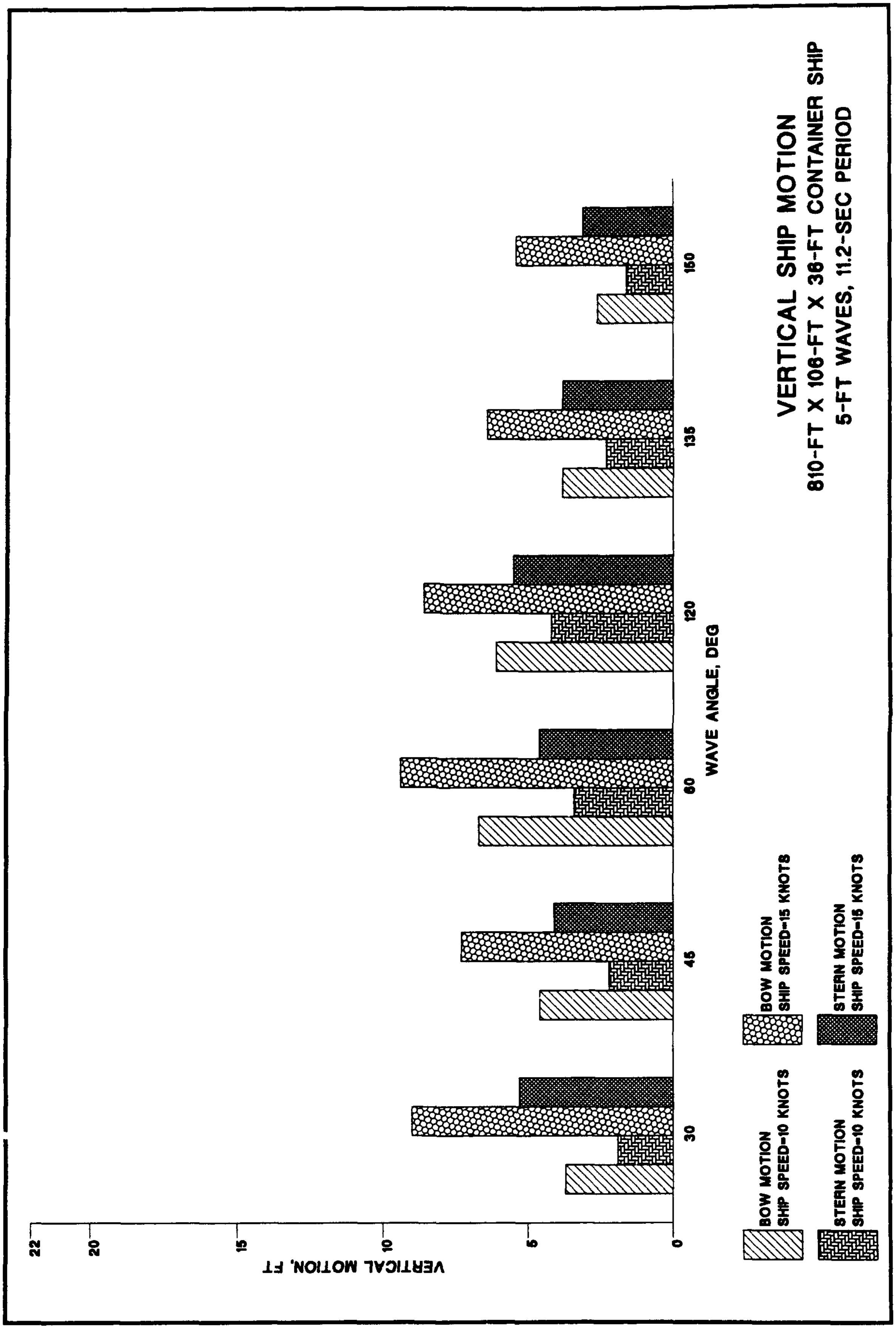
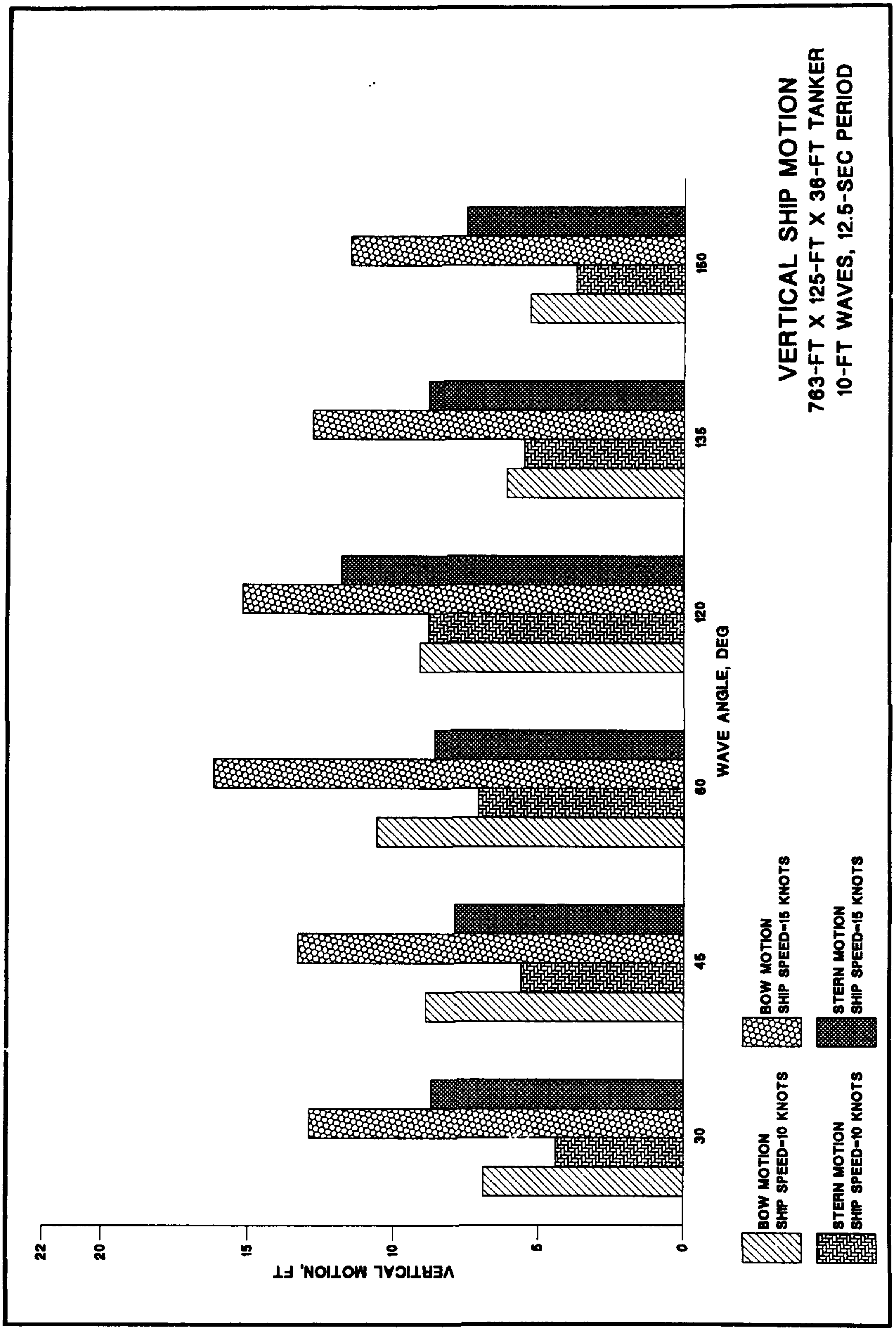

VERTICAL SHIP MOTION
810-FT X 106-FT X 38-FT CONTAINER SHIP
5-FT WAVES, 11.2-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION SHIP SPEED-10 KNOTS
BOW MOTION SHIP SPEED-15 KNOTS
STERN MOTION SHIP SPEED-10 KNOTS
STERN MOTION SHIP SPEED-15 KNOTS

Plate 144


VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
10-FT WAVES, 12.5-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED=10 KNOTS
BOW MOTION
SHIP SPEED=15 KNOTS
STERN MOTION
SHIP SPEED=10 KNOTS
STERN MOTION
SHIP SPEED=15 KNOTS

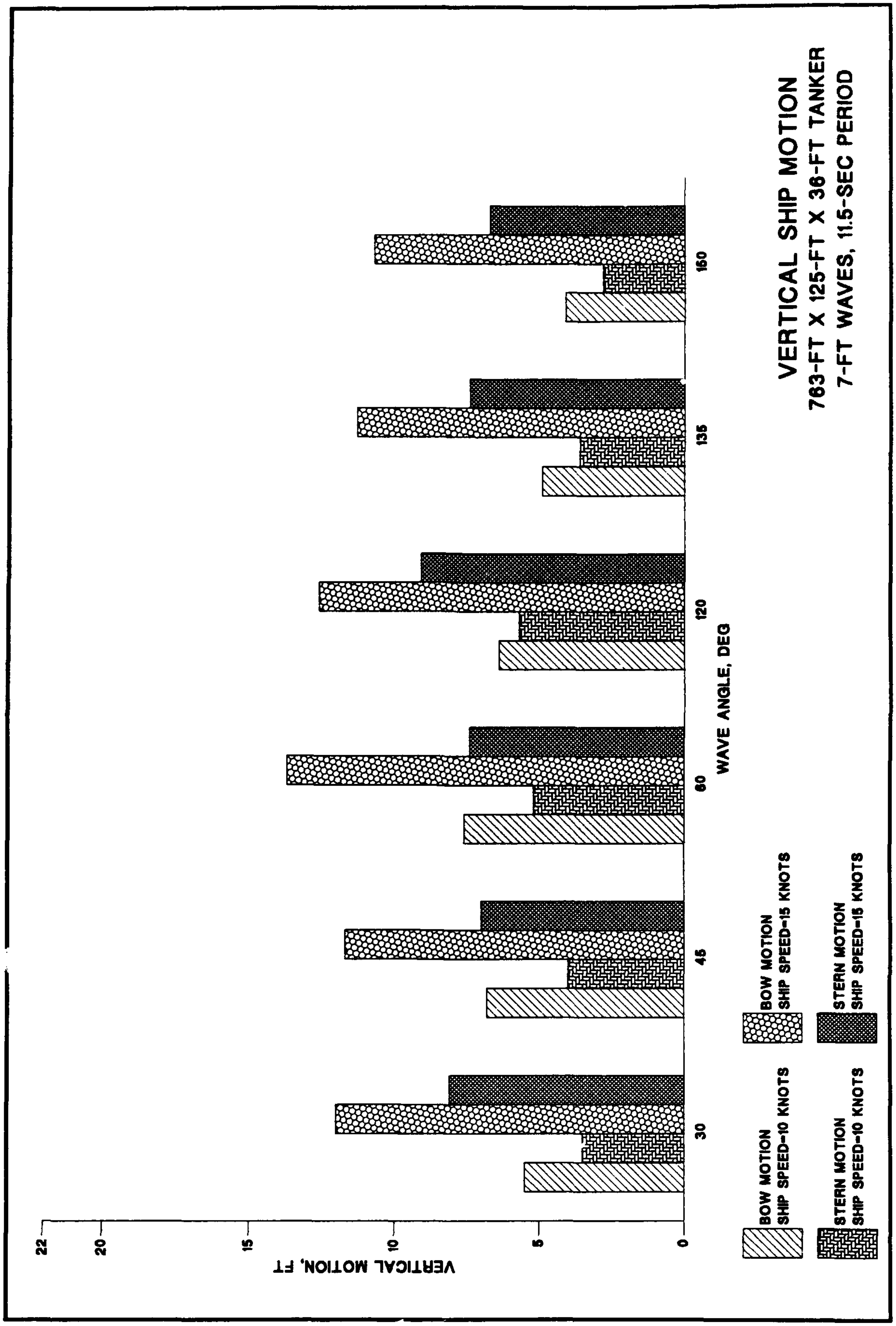
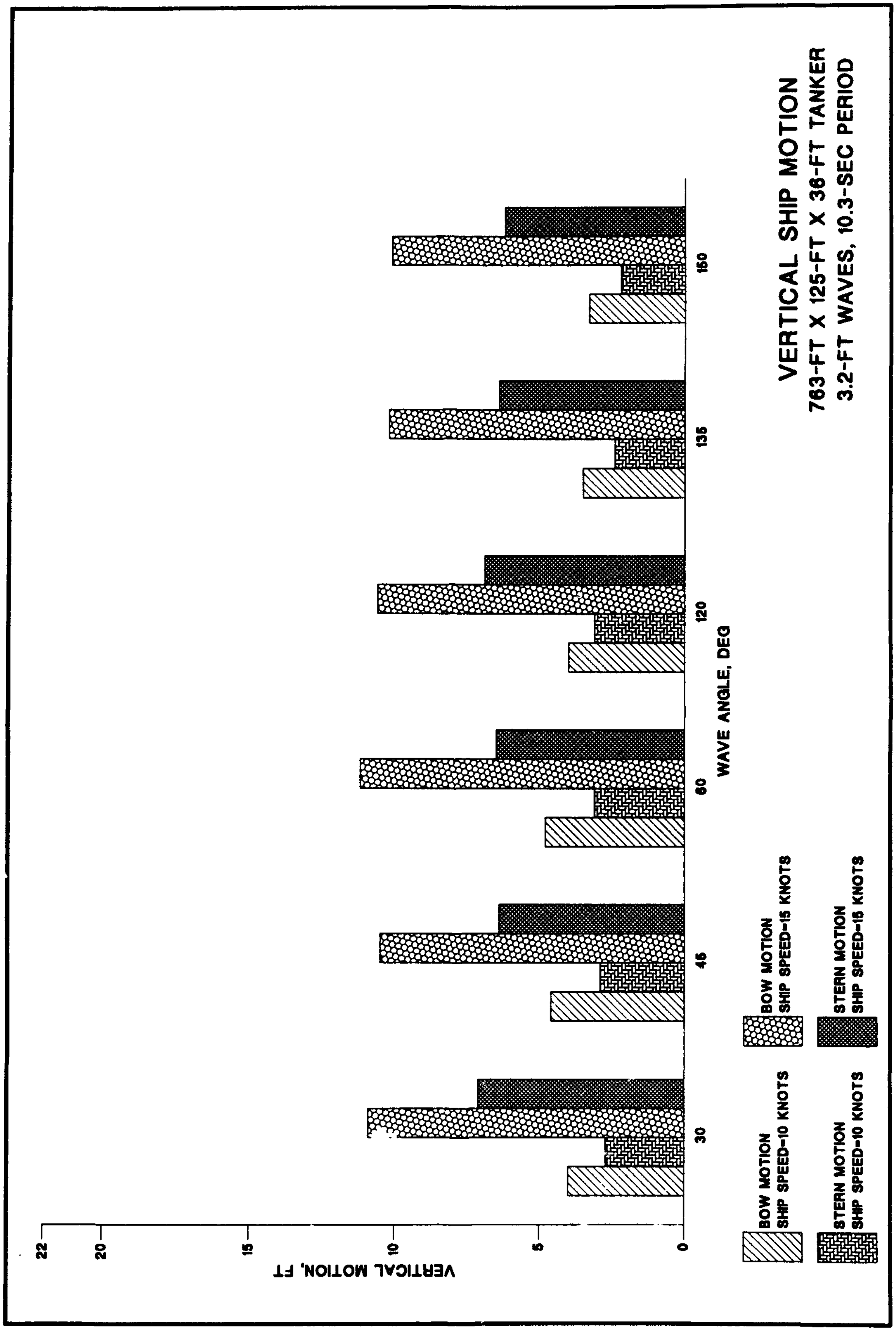

VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
7-FT WAVES, 11.5-SEC PERIOD
VERTICAL MOTION, FT
WAVE ANGLE, DEG
0
5
10
15
20
22
30
45
60
120
135
160
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

Plate 146


VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
3.2-FT WAVES, 10.3-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

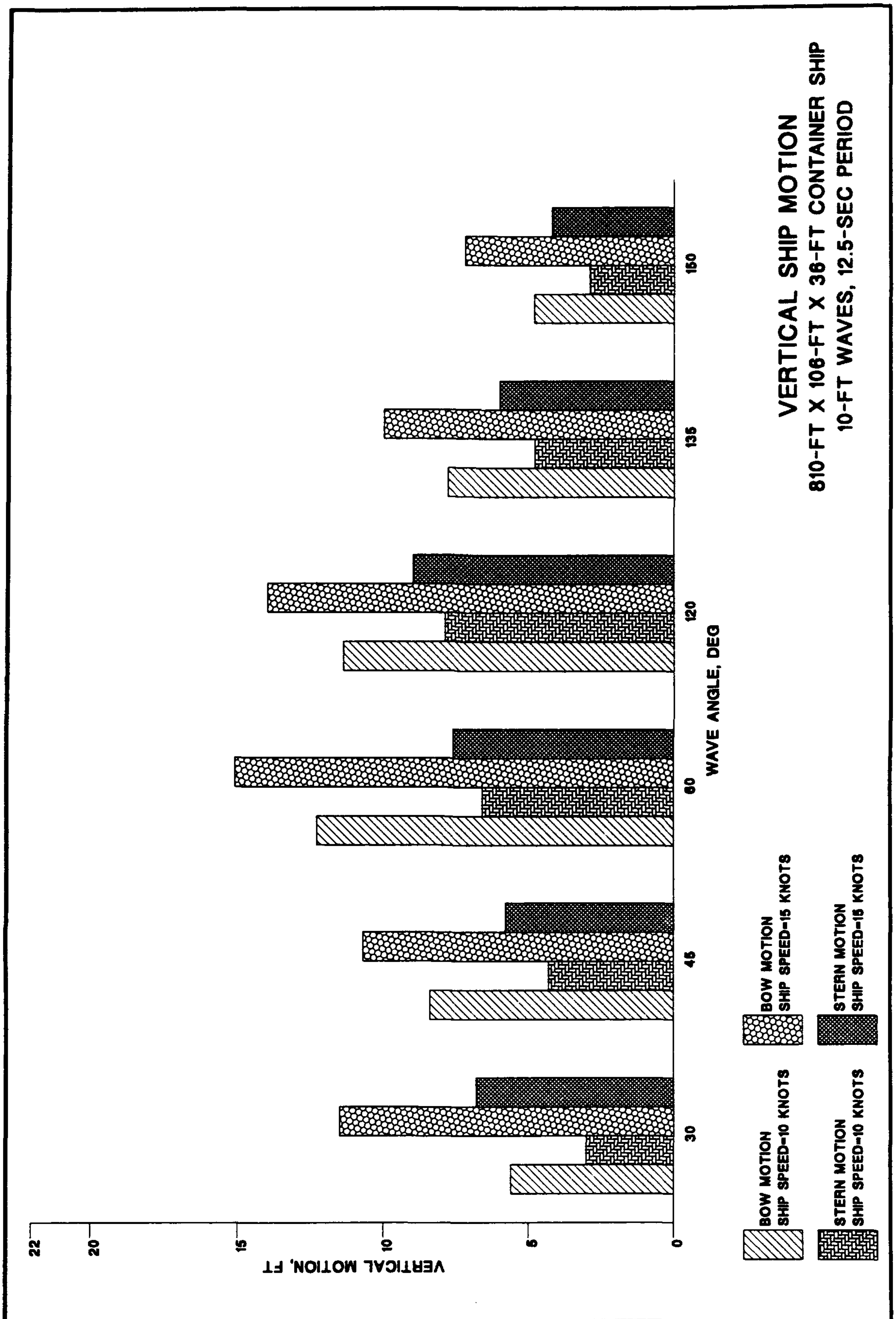
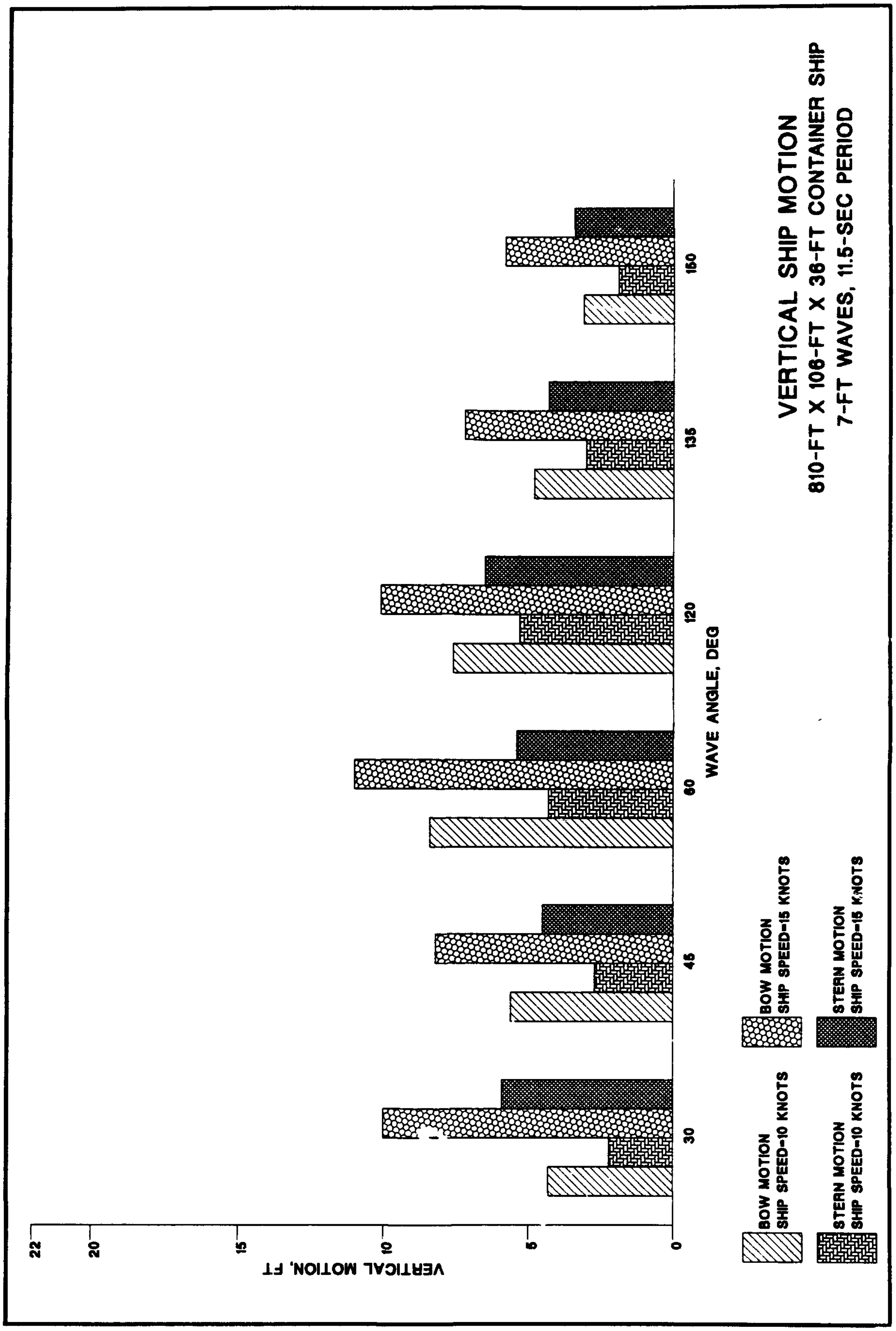
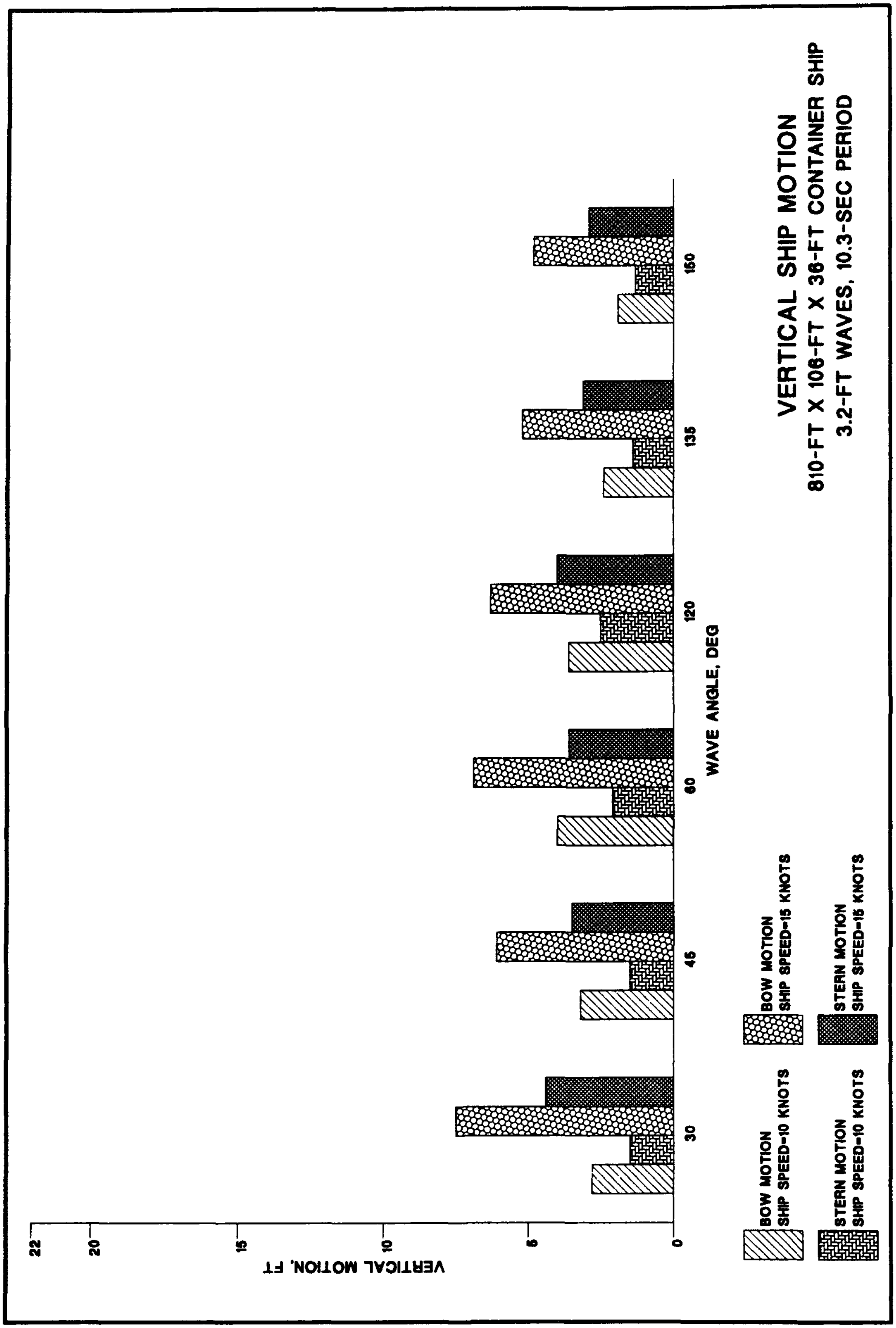

VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
10-FT WAVES, 12.5-SEC PERIOD
VERTICAL MOTION, FT
WAVE ANGLE, DEG
0
5
10
15
20
22
30
45
60
120
135
150
BOW MOTION SHIP SPEED-10 KNOTS
BOW MOTION SHIP SPEED-15 KNOTS
STERN MOTION SHIP SPEED-10 KNOTS
STERN MOTION SHIP SPEED-15 KNOTS

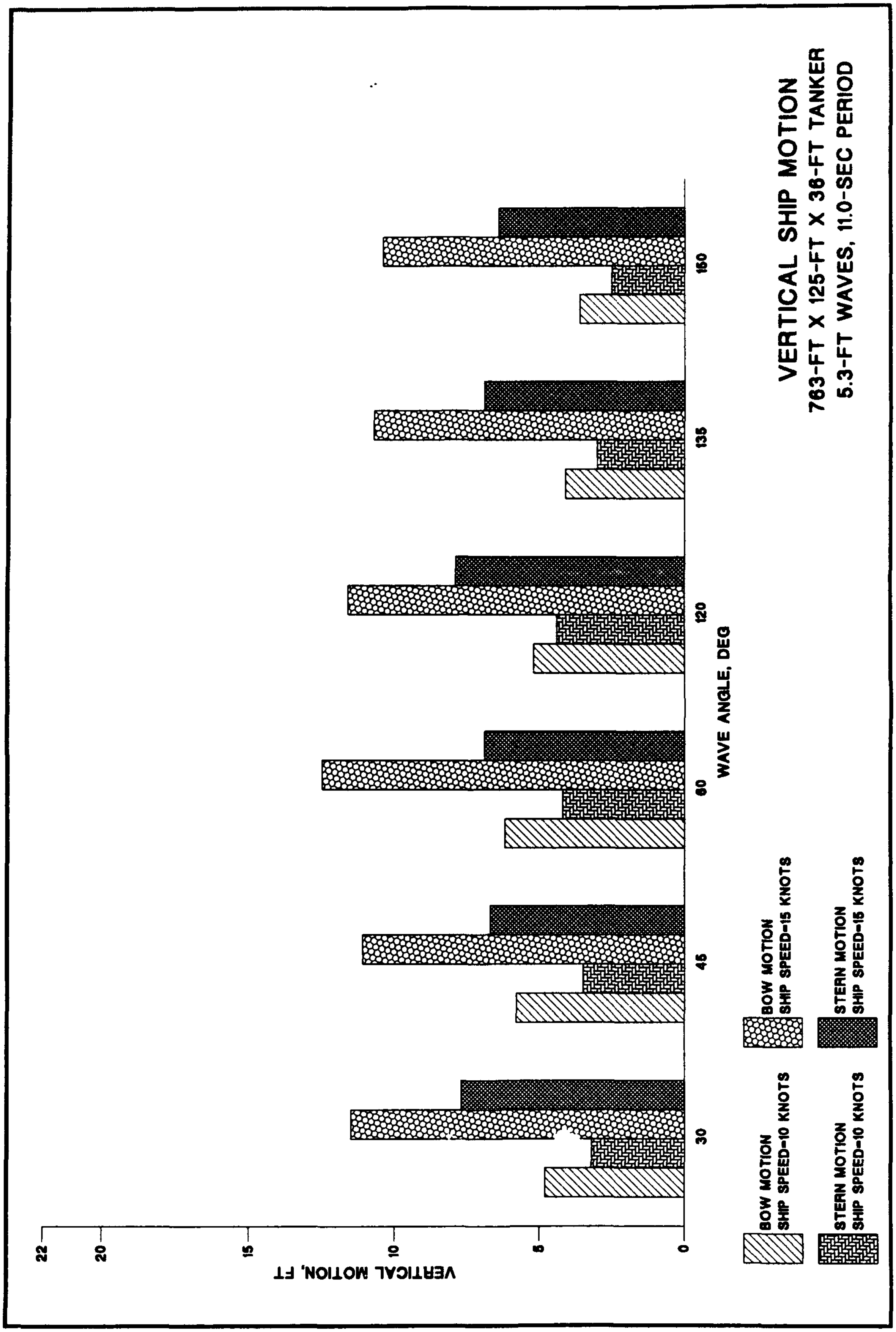
Plate 148

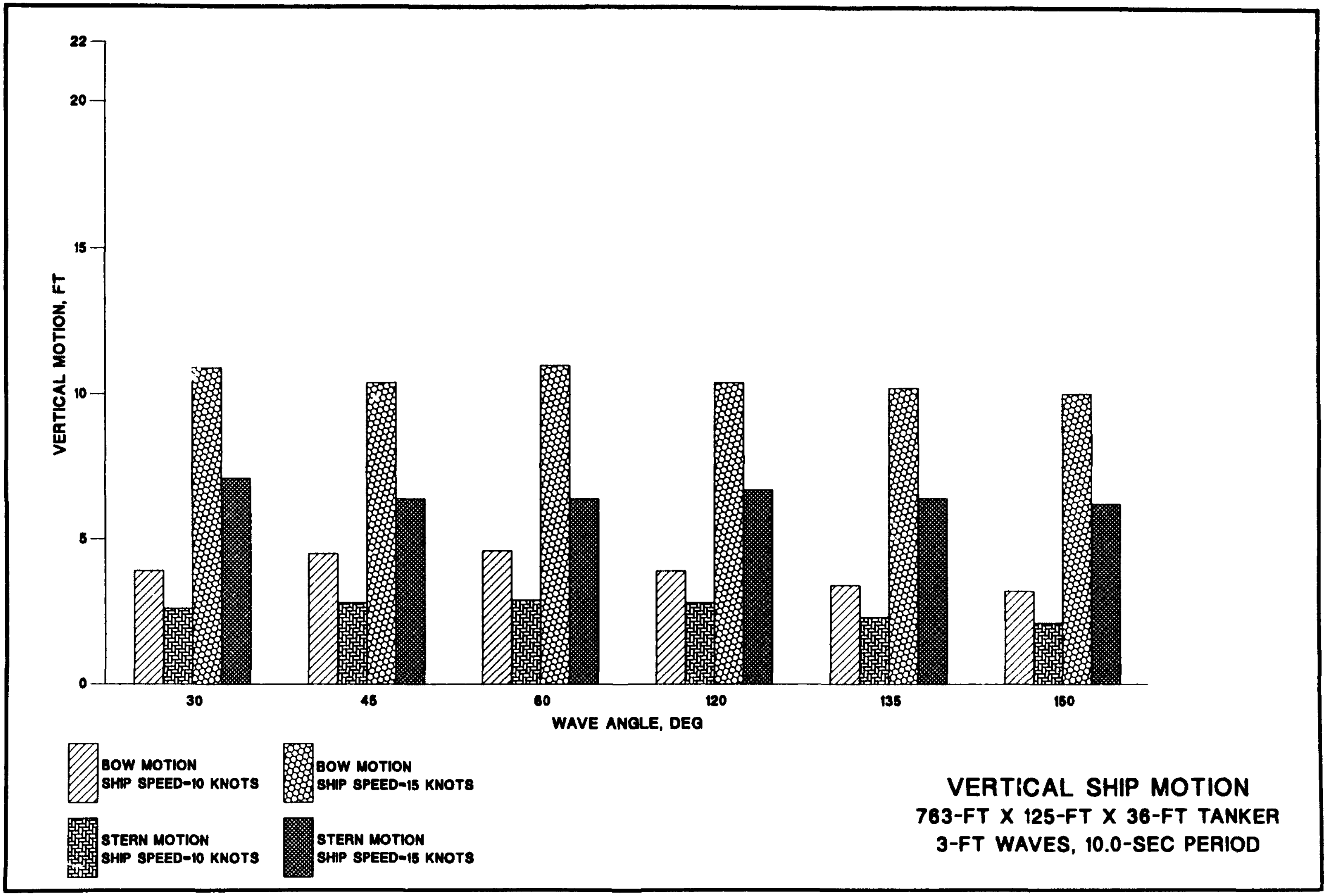

VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
7-FT WAVES, 11.5-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

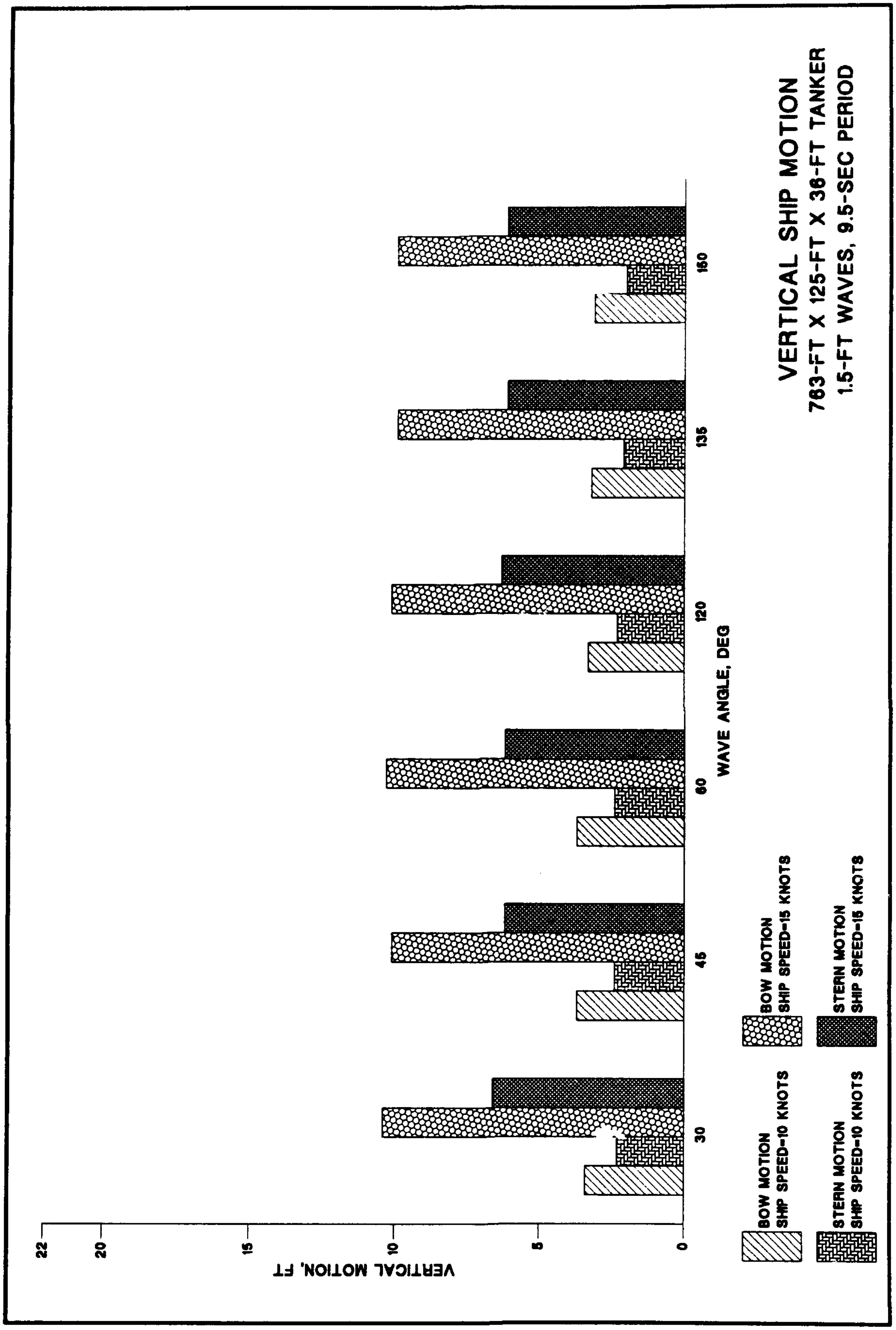


VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
3.2-FT WAVES, 10.3-SEC PERIOD
VERTICAL MOTION, FT
WAVE ANGLE, DEG
0
5
10
15
20
22
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

Plate 150

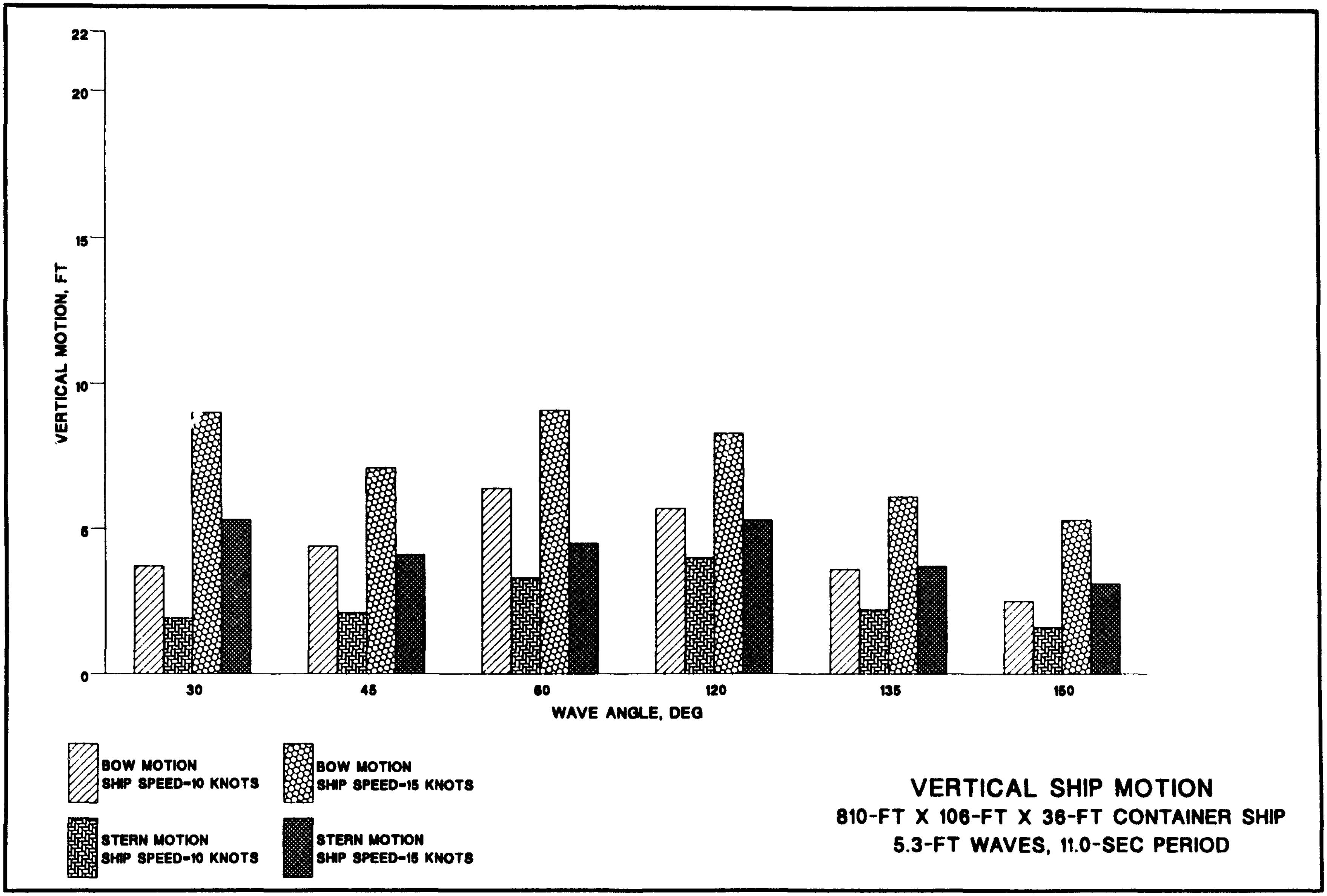

VERTICAL SHIP MOTION
763-FT X 125-FT X 38-FT TANKER
5.3-FT WAVES, 11.0-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
90
120
135
150
BOW MOTION SHIP SPEED-10 KNOTS
BOW MOTION SHIP SPEED-15 KNOTS
STERN MOTION SHIP SPEED-10 KNOTS
STERN MOTION SHIP SPEED-15 KNOTS

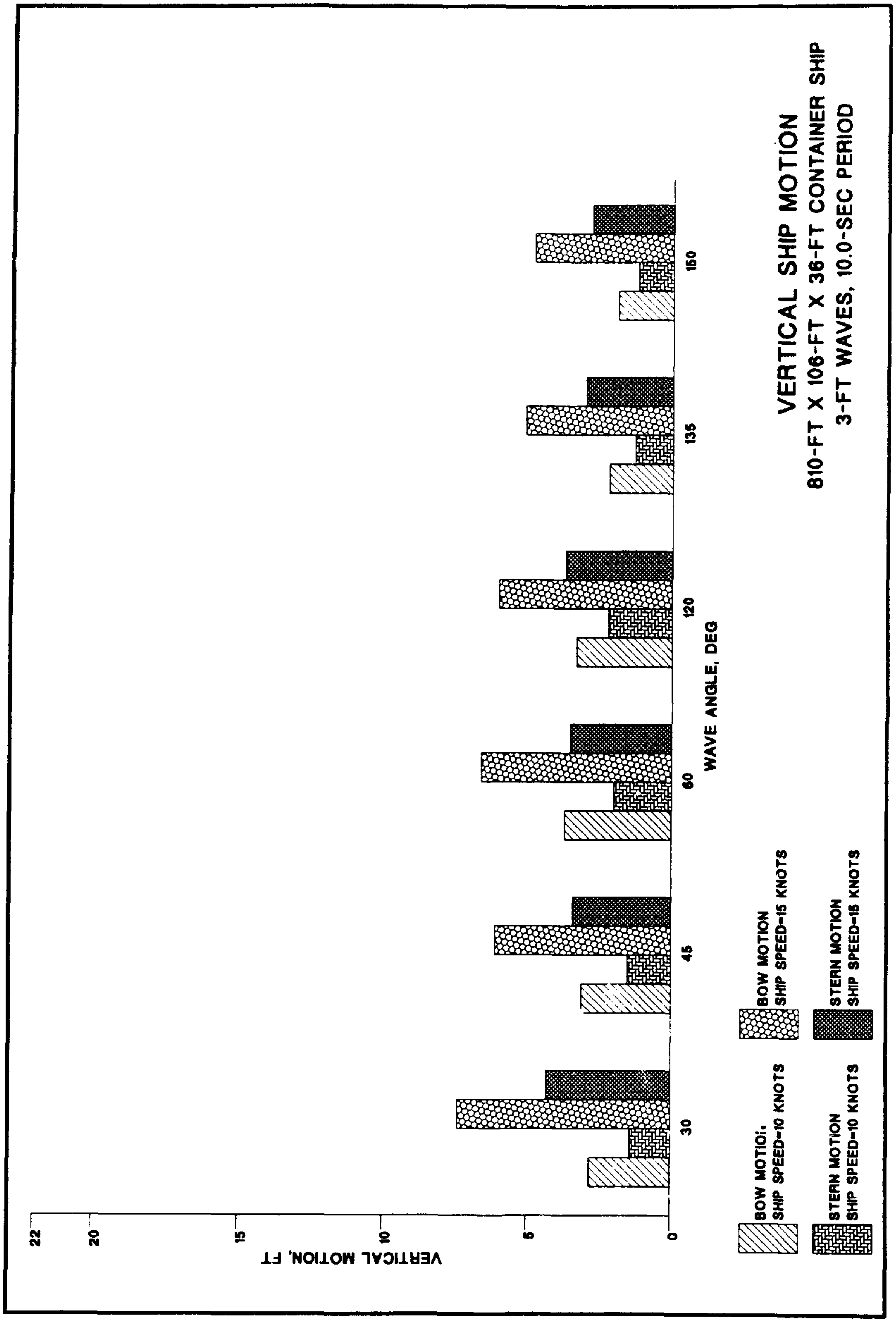

22
20
15
10
5
0
VERTICAL MOTION, FT
30
45
60
120
135
150
WAVE ANGLE, DEG
BOW MOTION
SHIP SPEED=10 KNOTS
BOW MOTION
SHIP SPEED=15 KNOTS
STERN MOTION
SHIP SPEED=10 KNOTS
STERN MOTION
SHIP SPEED=15 KNOTS
VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
3-FT WAVES, 10.0-SEC PERIOD

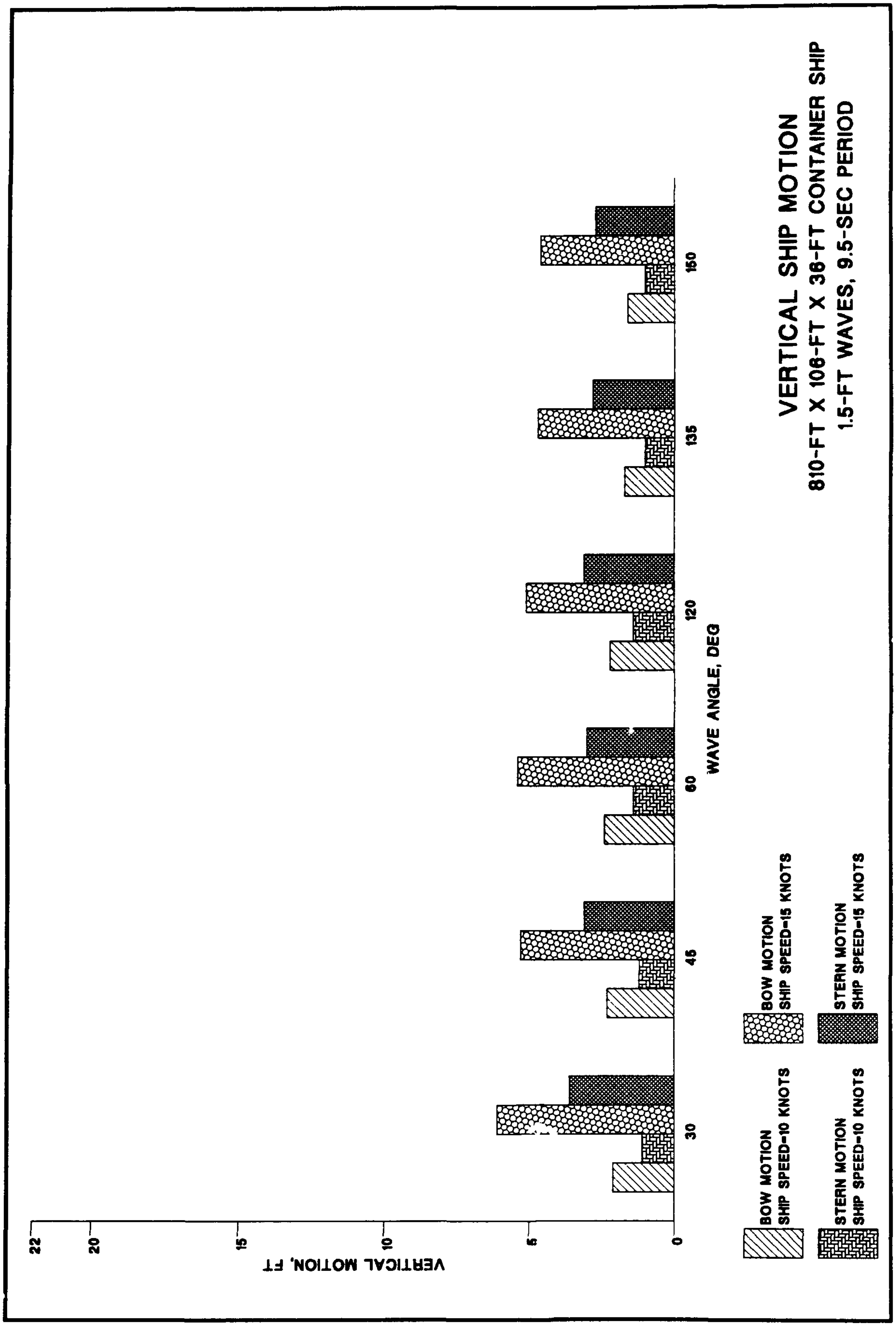


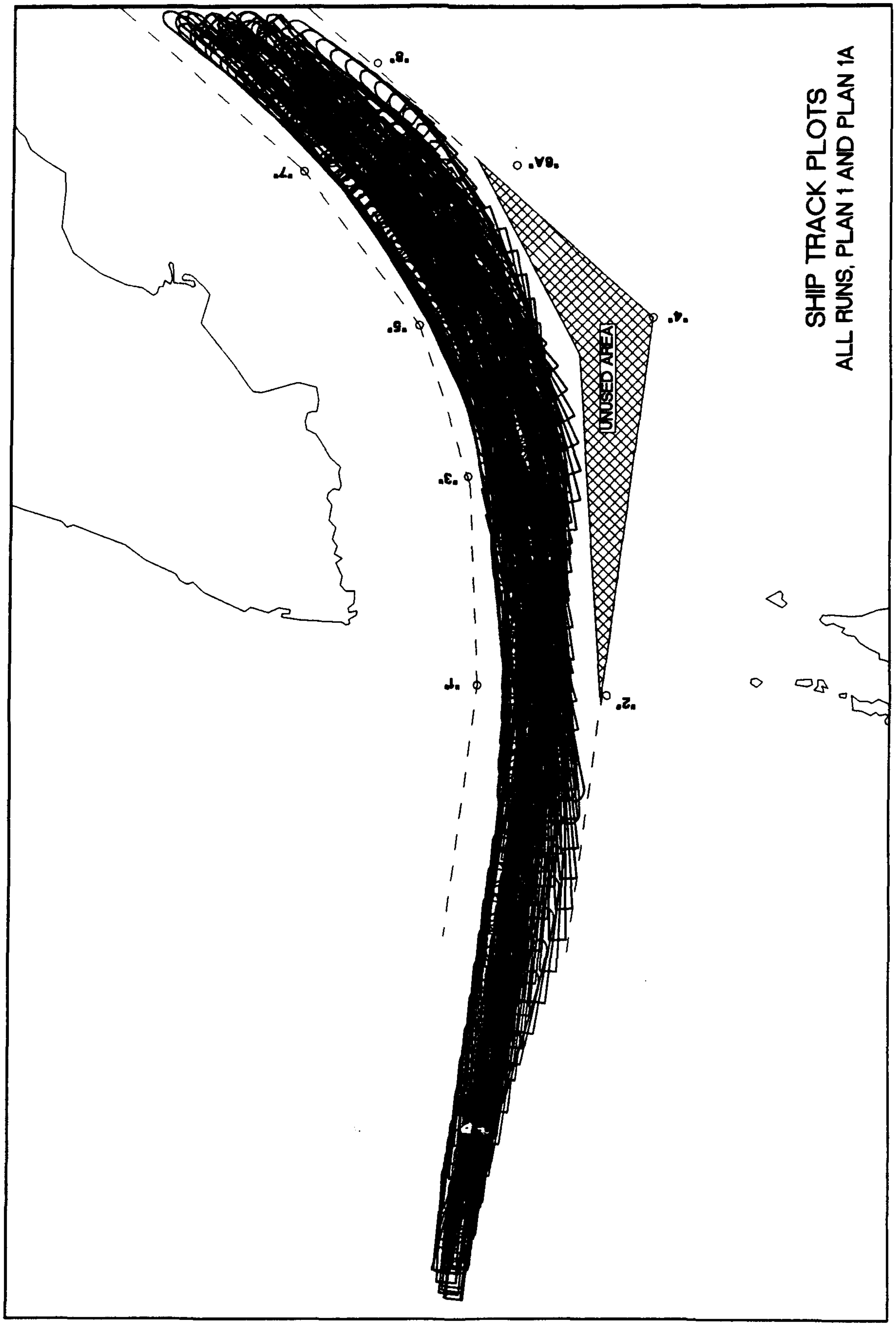
VERTICAL SHIP MOTION
763-FT X 125-FT X 36-FT TANKER
1.5-FT WAVES, 9.5-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS

Plate 154


VERTICAL MOTION, FT
22
20
15
10
5
0
30
45
60
120
135
150
WAVE ANGLE, DEG
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS
VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
5.3-FT WAVES, 11.0-SEC PERIOD


VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
3-FT WAVES, 10.0-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS


VERTICAL SHIP MOTION
810-FT X 106-FT X 36-FT CONTAINER SHIP
1.5-FT WAVES, 9.5-SEC PERIOD
VERTICAL MOTION, FT
0
5
10
15
20
22
WAVE ANGLE, DEG
30
45
60
120
135
150
BOW MOTION
SHIP SPEED-10 KNOTS
BOW MOTION
SHIP SPEED-15 KNOTS
STERN MOTION
SHIP SPEED-10 KNOTS
STERN MOTION
SHIP SPEED-15 KNOTS


SHIP TRACK PLOTS
ALL RUNS, PLAN 1 AND PLAN 1A
UNUSED AREA

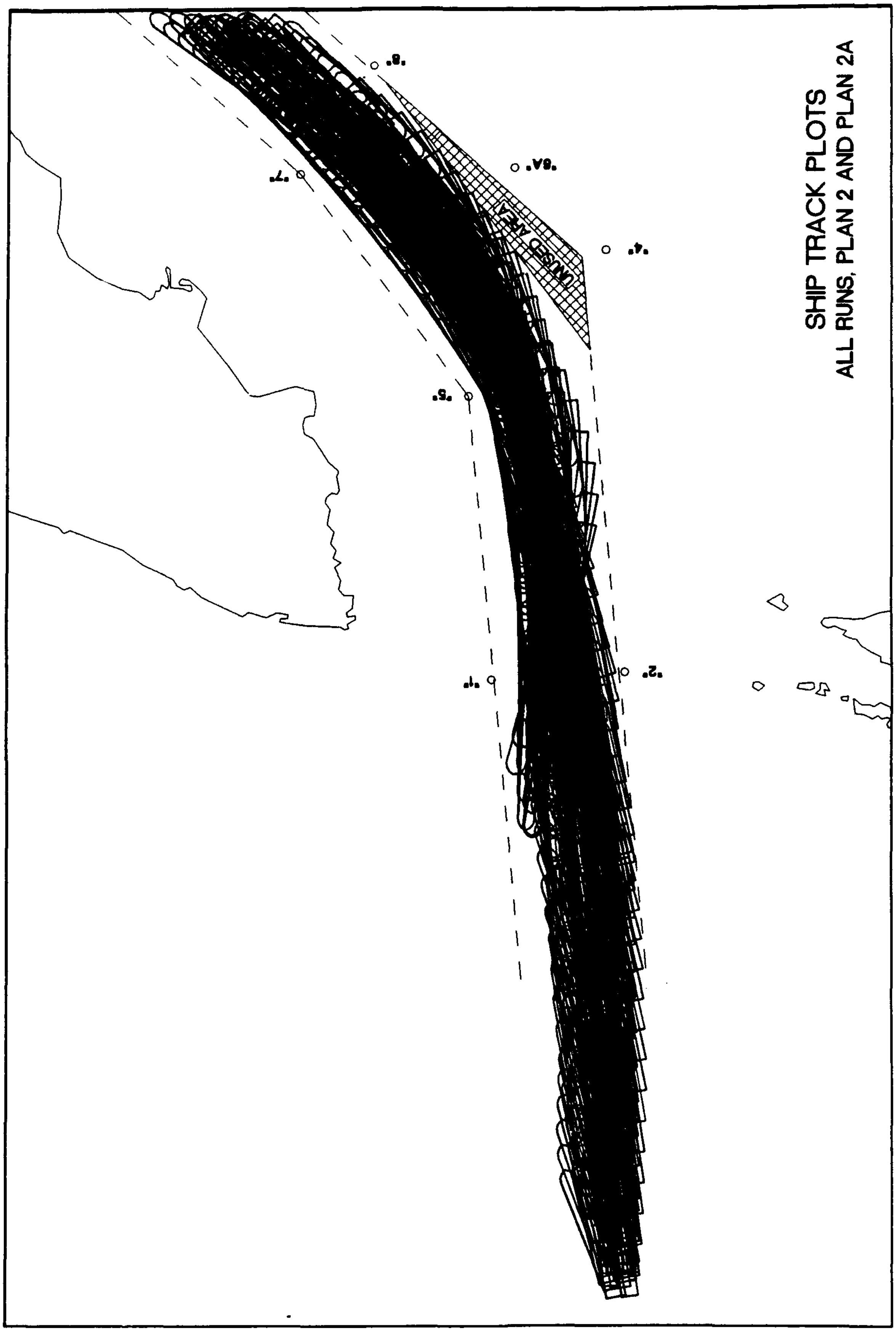

SHIP TRACK PLOTS
ALL RUNS, PLAN 2 AND PLAN 2A
UNUSED AREA
8
8A
7
4
5
1
2

Plate 158

Appendix A
Flow Model Testing

The Numerical Model

The Corps' numerical modeling system, "Open-Channel Flow and Sedimentation, TABS-2",[1] was used in the evaluation of the impact of channel deepening at San Juan, Puerto Rico. The hydrodynamic predictions were used in the ship simulator evaluation of the proposed channel improvements. The numerical model used was "A Two-Dimensional Model for Free Surface Flows (RMA-2V)." The code employs the finite element method to solve the depth-integrated governing equations.

Computational Meshes of the San Juan Harbor

The computational mesh for the base condition included all the features shown on the National Oceanic and Atmospheric Administration (NOAA), NOS Nautical Chart No. 25670, August 30, 1986 (34th edition), Bahia de San Juan, map scale 1:10,000 (Figure A1 shows the study area). Since the depths drop off very rapidly offshore (18 to >150 ft at the boundary) only a relatively small ocean was needed for this hydrodynamic study. The mesh was initially drawn by hand to ensure properly sized elements and reasonable depth changes across the elements. The completed mesh was overlayed with a CAD drawing of the shoreline and channels to ensure proper alignment of the numerical model mesh. All depths were from the NOAA chart used in this study. These depths were referenced to mean low water (MLW). The depths were verified with surveys supplied by the Jacksonville District. All channels were placed in the model at authorized or proposed depths. The base mesh is shown in Figure A2. It had 1720 elements and 5306 nodes.

[1] William A. Thomas and William H. McAnally, Jr. (1985). "User's Manual for the Generalized Computer Program System: Open-Channel Flow and Sedimentation, TABS-2; Main Text and Appendices A Through O," Instruction Report HL-85-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The two plan conditions required that some modifications be made to the base condition mesh. The differences in the meshes between base and the two plans were not extensive so comparisons could still be made with the computed velocities and water surface elevations. The entrance channel was either widened (Plan 1) or realigned (Plan 2). Also other channels within San Juan Harbor were either modified in width or alignment. These changes are discussed in the main text. The Plan 1 mesh is shown in Figure A3. The Plan 2 mesh is shown in Figure A4.

Model Validation

Since no field data could be located for boundary conditions, the model was operated with a tide predicted from the Tide Tables - East Coast of North and South America for 1991 (NOAA). To gain an insight into the tidal conditions at San Juan a histogram of the predicted tidal range versus percent occurrence was generated (Figure A5). This was accomplished by determining the difference between consecutive high and low waters over the entire year of data presented in the tide tables. Then tidal ranges with a similar value were grouped and summed. Percentages of occurrence were then calculated and graphed. Since the tidal ranges were so small it was decided to use the maximum predicted tide (maximum range 1.8 ft). There was only one predicted tide during 1991 with that range. An actual predicted tide was used for a period that included this maximum tide range (Figure A6). The procedure shown in the tide tables was used to develop the tide curve used. The straight line in Figure A6 is the baseline to establish the shape of the actual predicted tide.

There was no phase change between the model ocean boundary and the interior of the harbor. Therefore no phase adjustment had to be made to the boundary tide. The tide produced very small velocities throughout the harbor. A site visit to San Juan and the San Juan local pilots substantiated these small velocities. Based on these observations and discussions, it was decided that no field data would be collected for model verification. Therefore the boundary conditions used initially were the final conditions used for all three test cases (Base, Plan 1, and Plan 2).

Test Procedures and Results

The Base and two Plan conditions were operated with the same boundary conditions. The surface elevations and velocities were compared at several key locations in San Juan Harbor (Figure A7). The response of the harbor indicated no phase difference in water surface elevations.

Figures A8 and A9 are Base to Plan 1 comparisons of surface elevations and velocity values. Figures A10 and A11 are the same station locations for Base to Plan 2 comparisons. No change in phase or amplitude as a result of plan changes were noted on the water surface elevation plots. At stations

represented by nodes 1582 and 1689 there were slight (less than 0.1 fps) changes in velocity between Base and both Plans. The other stations showed changes of no more than 0.05 fps. Table A1 shows the actual velocity values from the numerical model at maximum flood hours 9 and 22 and maximum ebb hours 4 and 16. Vector plots for the Base and Plans 1 and 2 are shown on Figures A12 - A23 for the two flood conditions hours 9 and 22 and the two ebb conditions hours 4 and 16. The maximum ebb and flood conditions hours 4 and 22 were used in the ship simulator evaluation of the channels.

CONCLUSIONS

In general the currents predicted for the Base condition were small. Most values were much less than the maximum flood condition at the entrance of 0.5 fps. In the interior the velocities were one-third that value or less. The largest changes were noted in the first bend of the entrance channel for the plan conditions; however, these changes were less than 0.1 fps. At the other stations the changes were less than 0.05 fps. Therefore at other than the entrance the tidal-generated currents were not significantly affected.

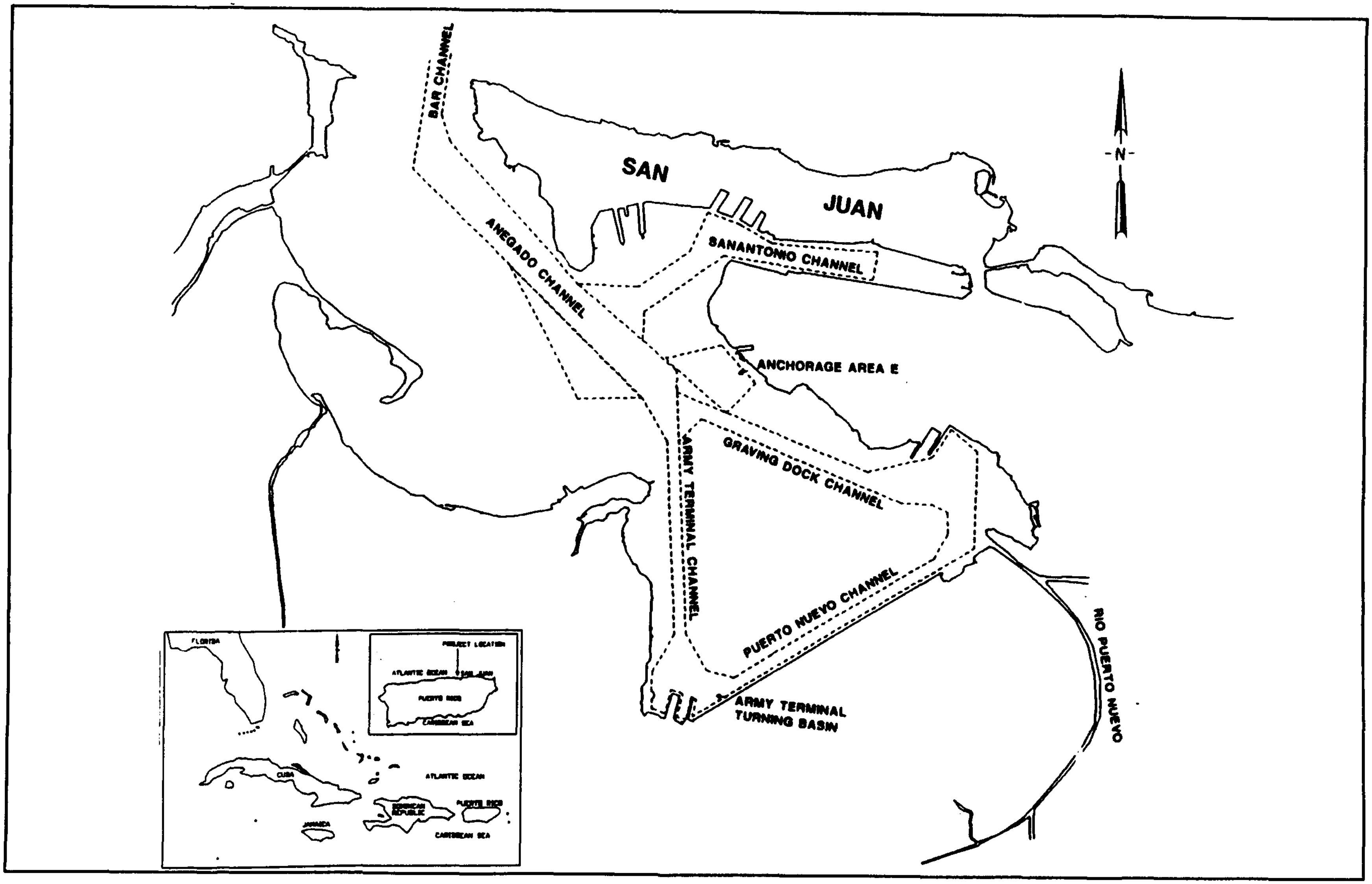


Figure A1. San Juan Harbor location map

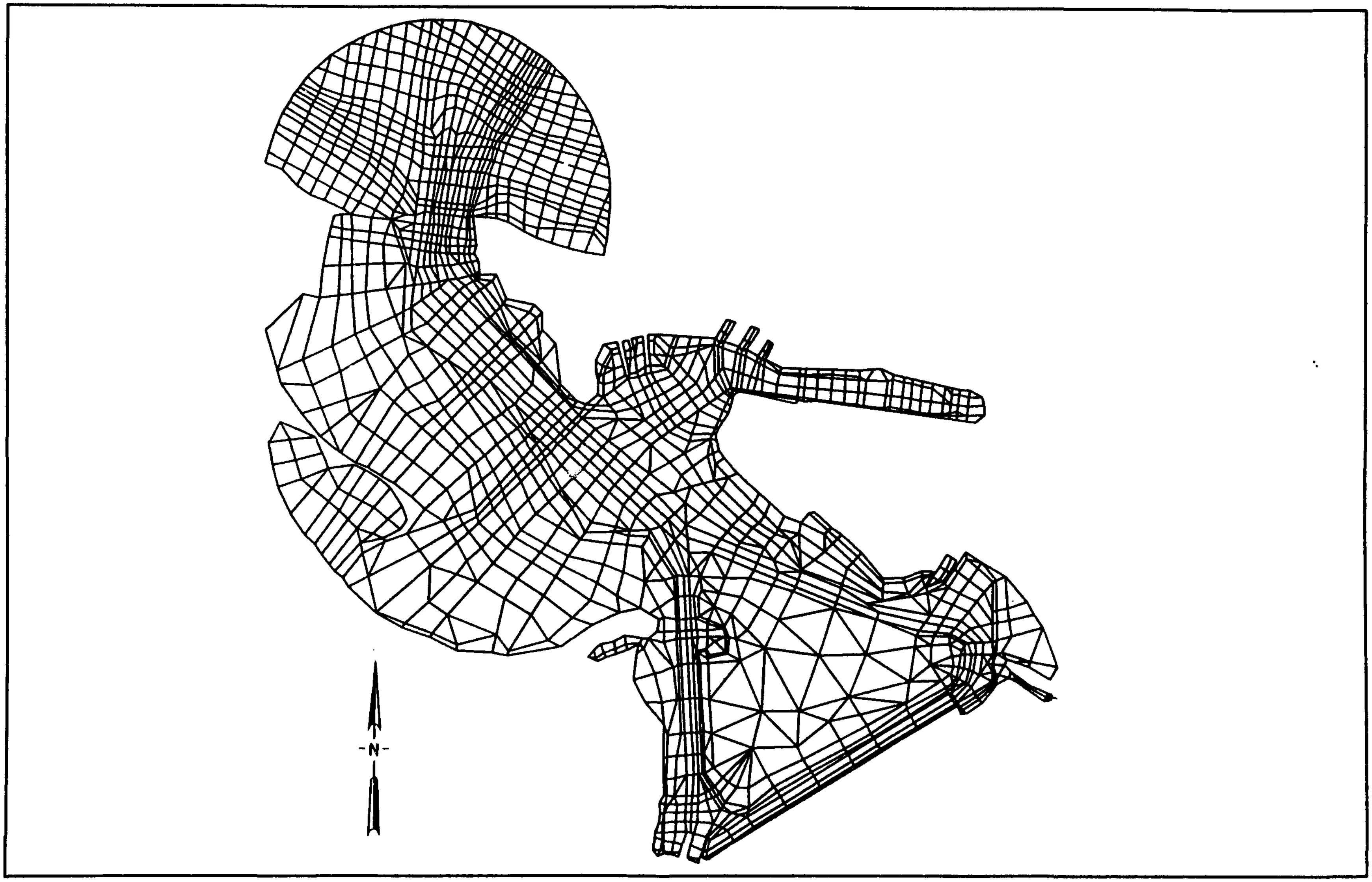


Figure A2. Numerical model mesh - base condition

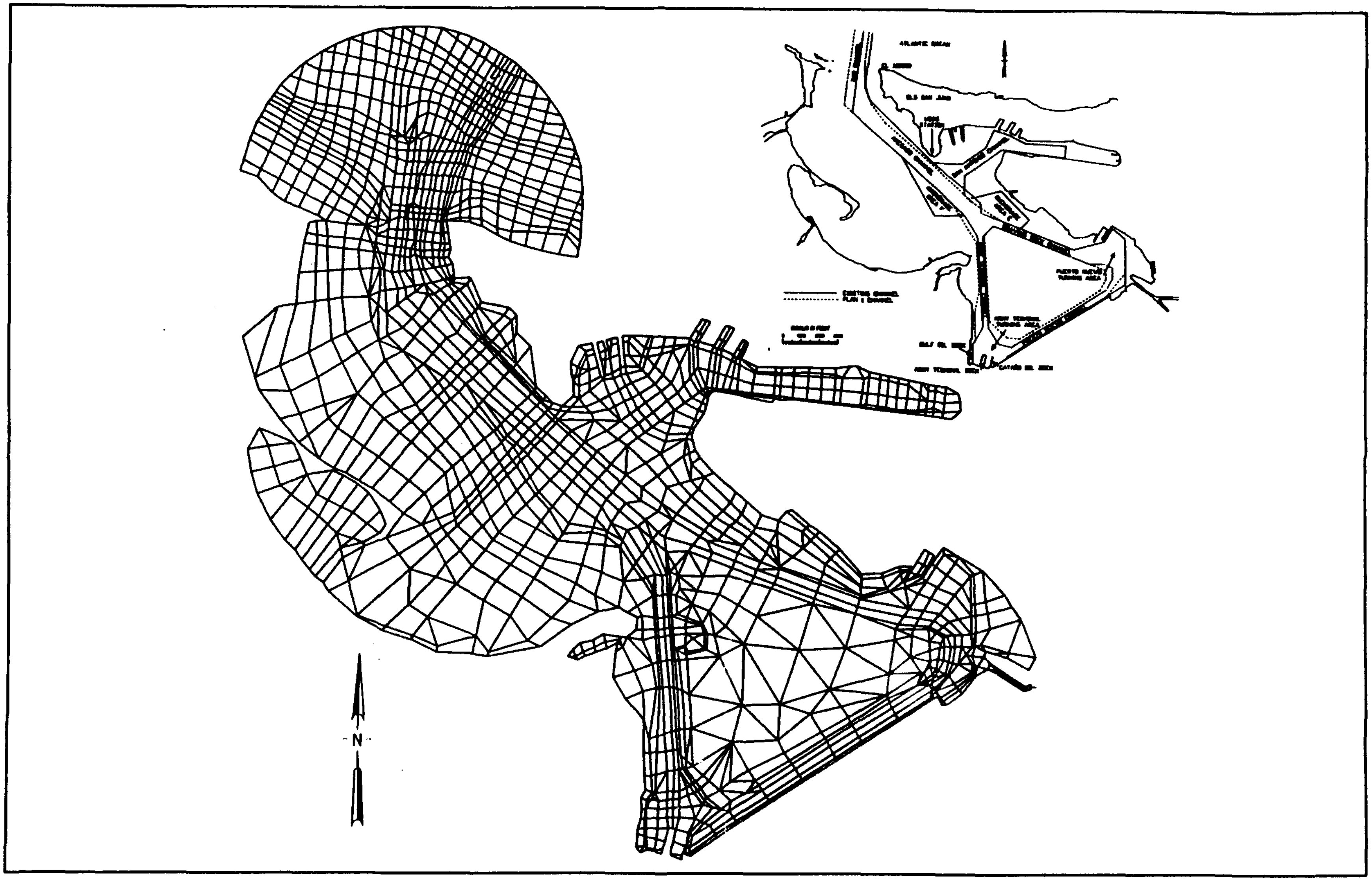


Figure A3. Numerical model mesh - plan 1

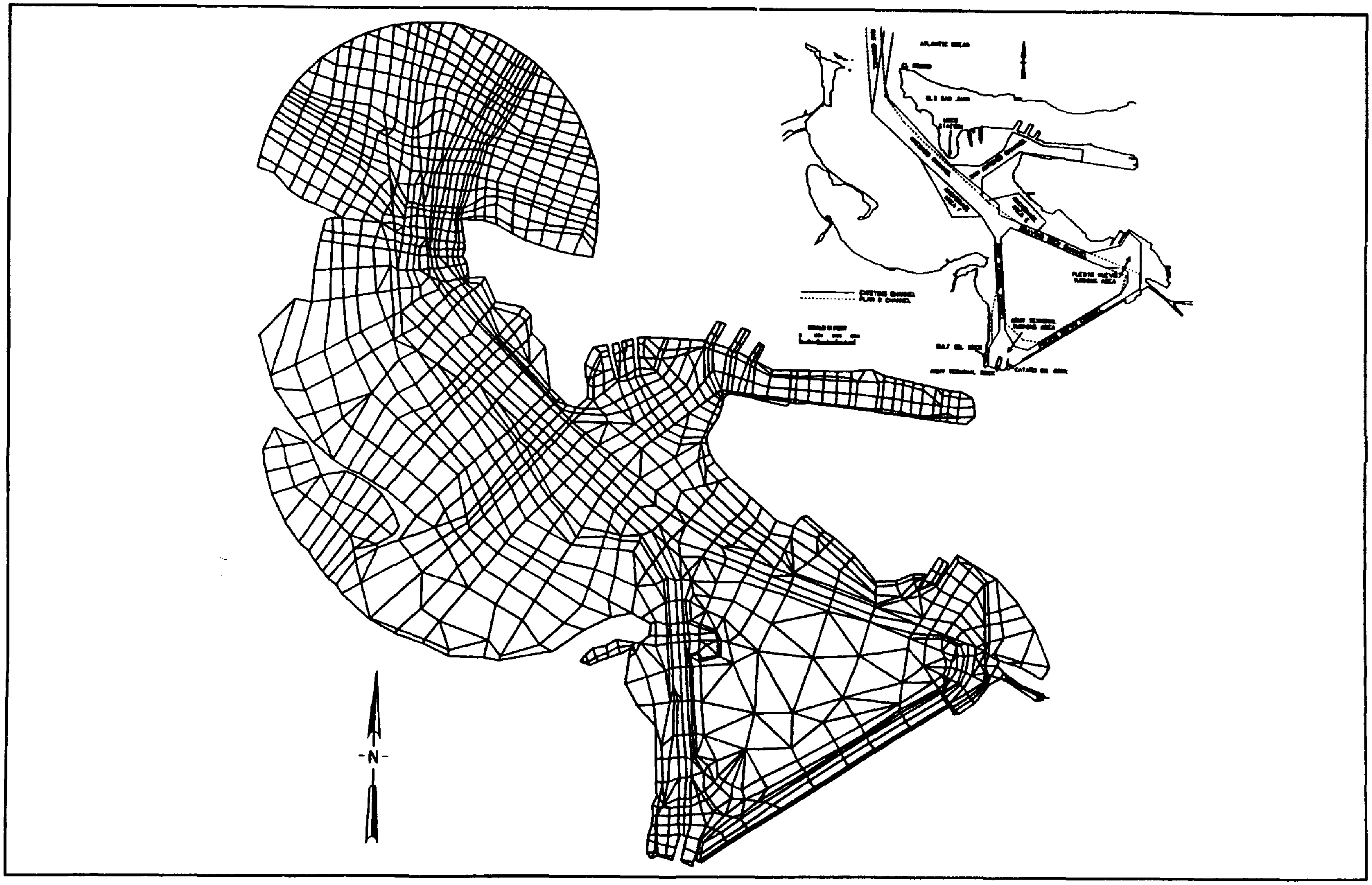


Figure A4. Numerical model mesh - plan 2

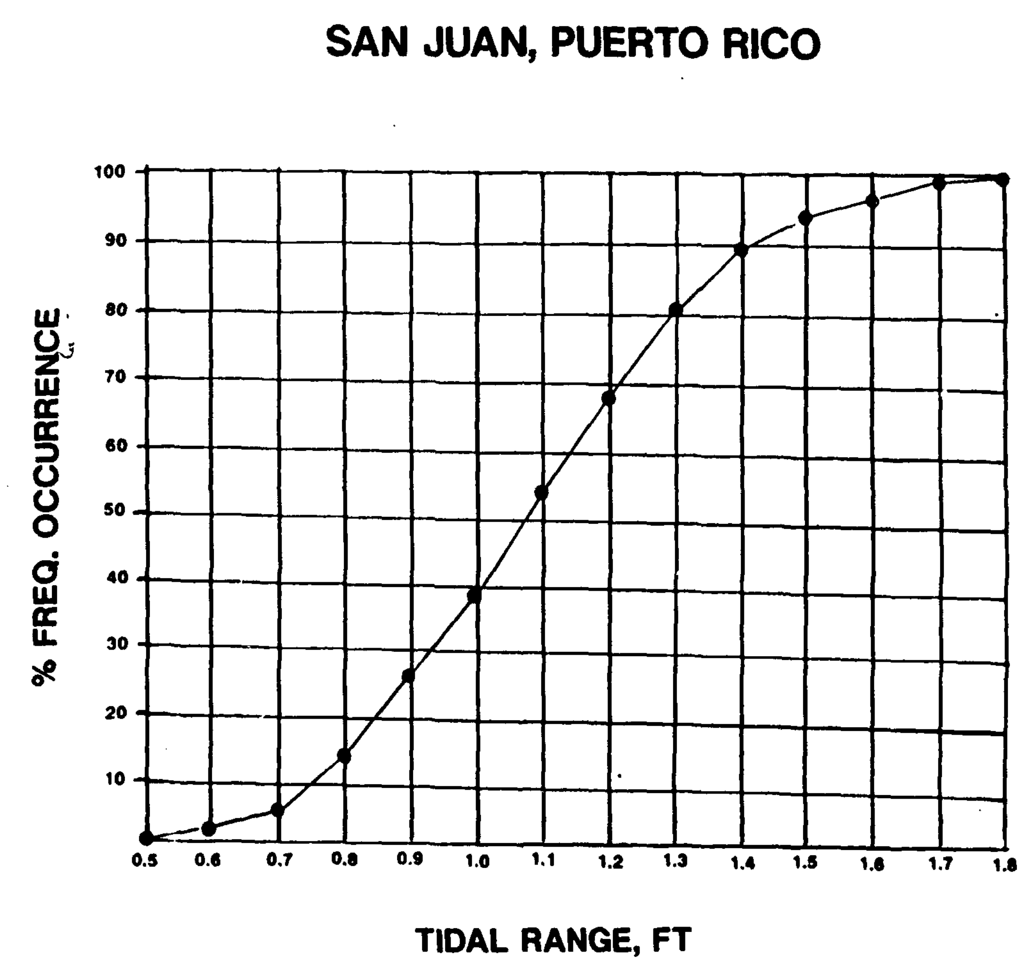


Figure A5. Histogram of tide range occurrence - 1991

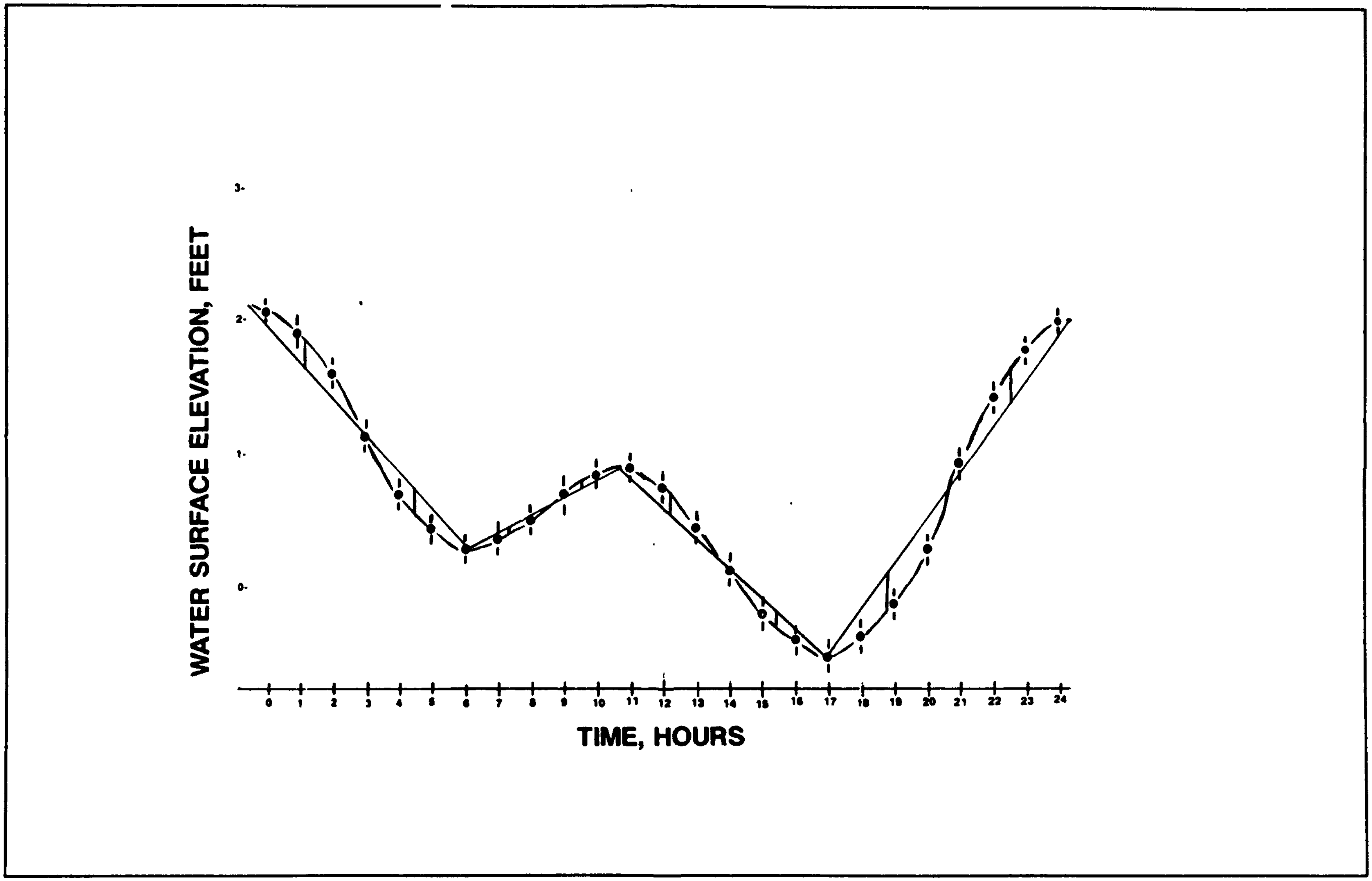


Figure A6. Predicted tide used for boundary conditions

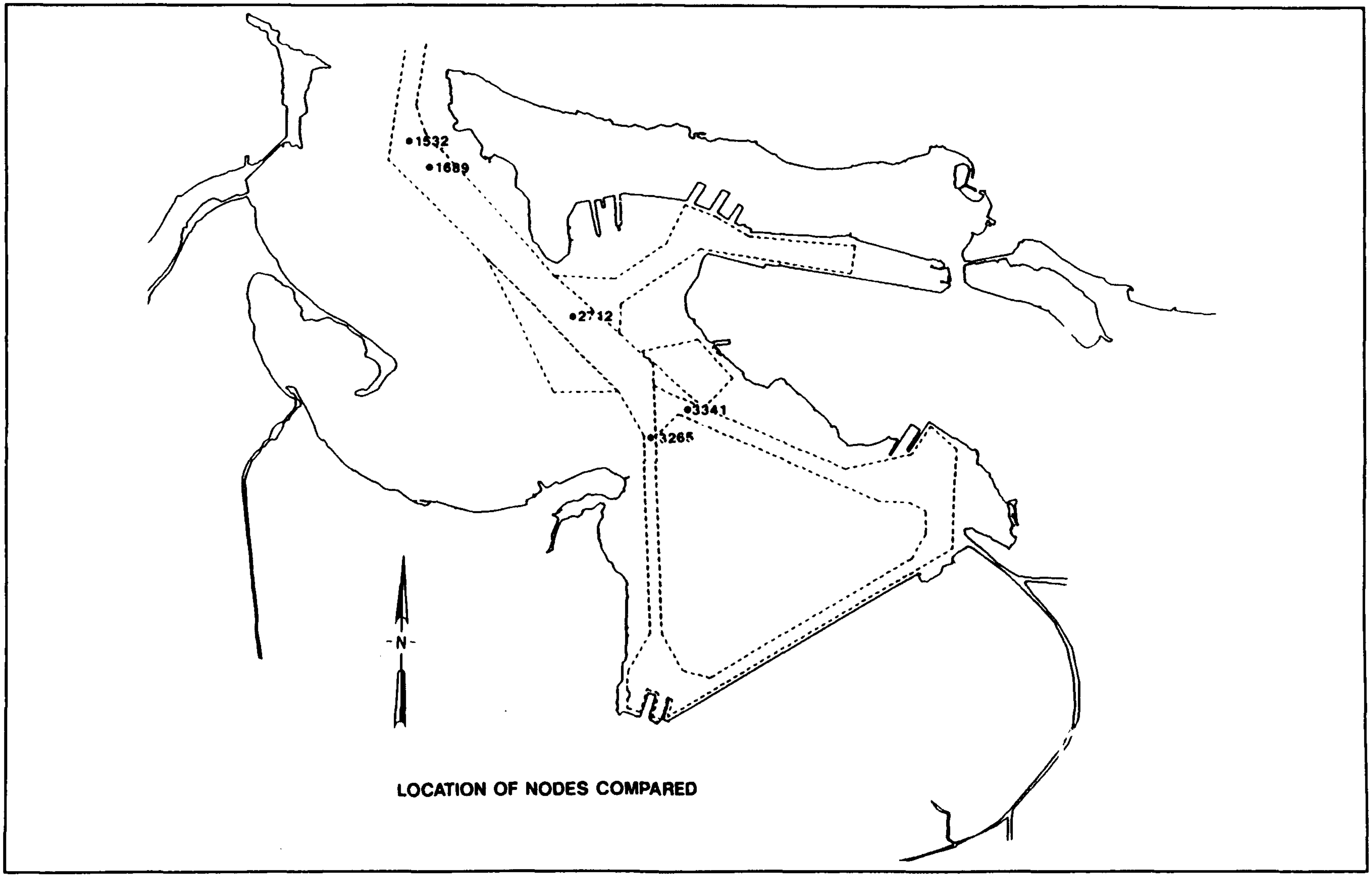
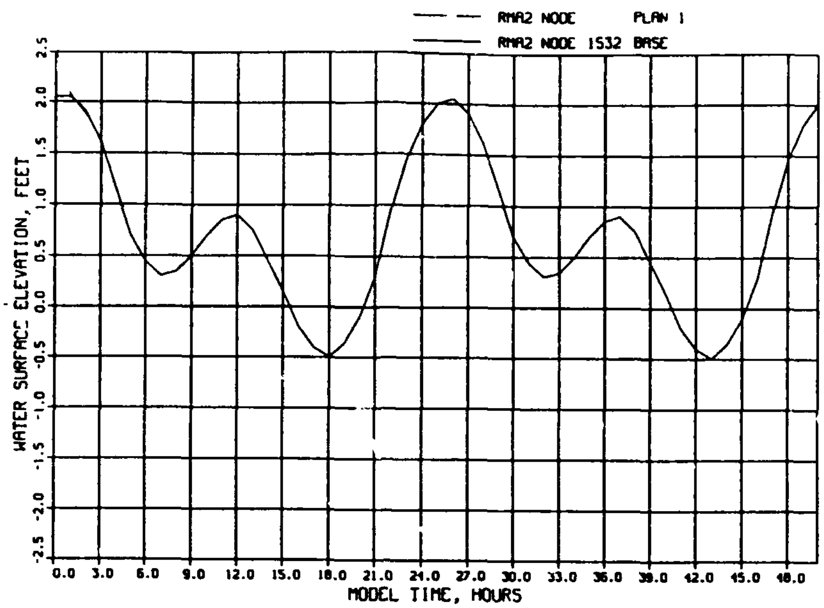


Figure A7. Location map of nodes compared



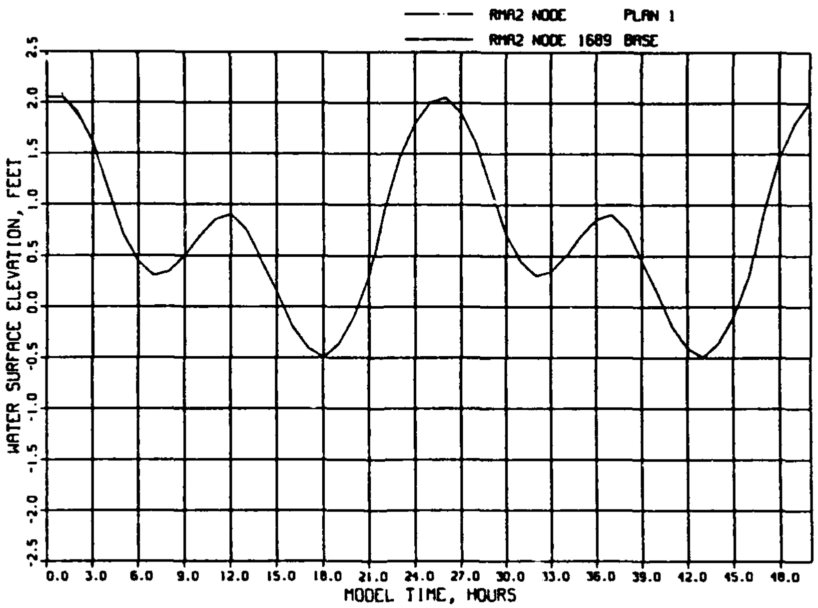
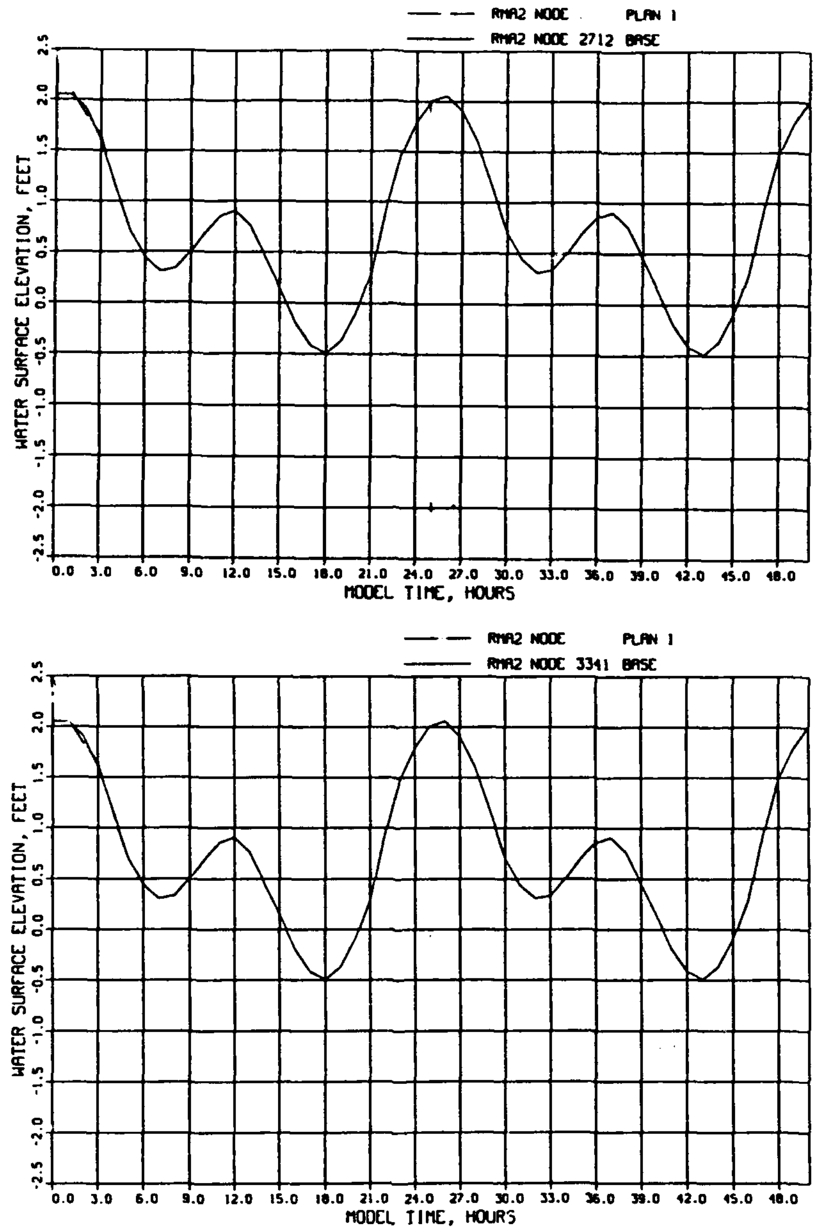


Figure A8. Water surface data, existing versus Plan 1 (Sheet 1 of 3)



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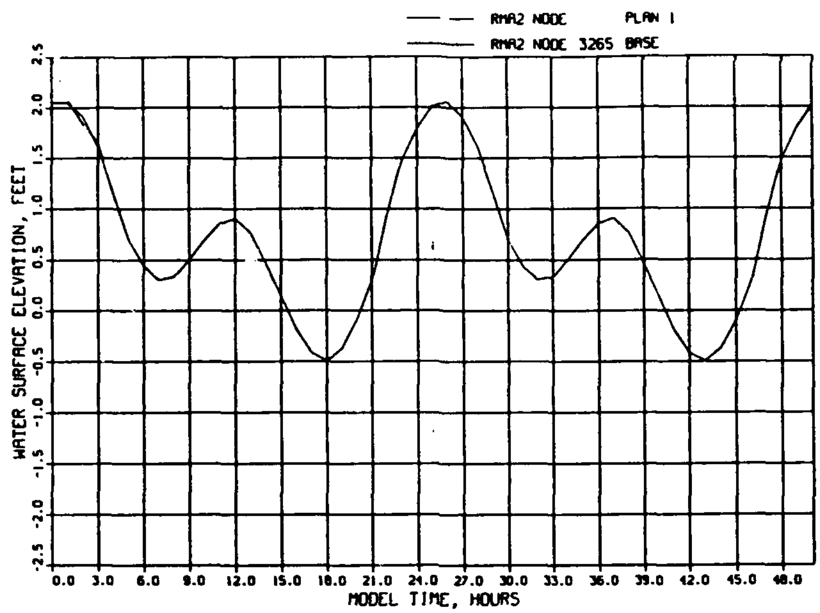

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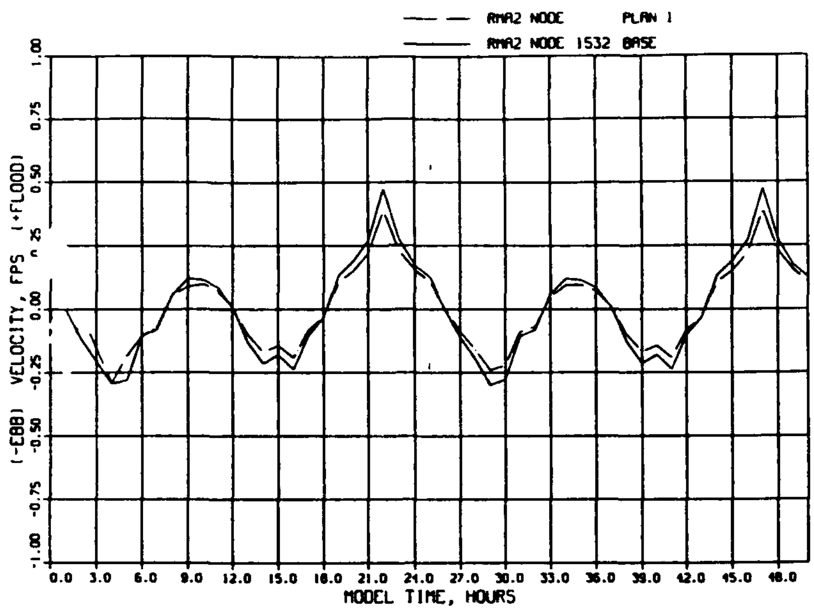


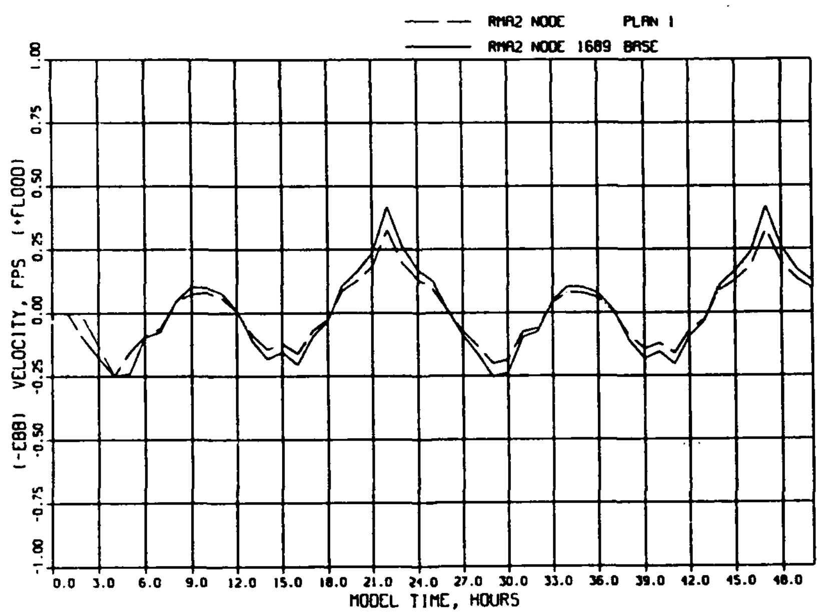
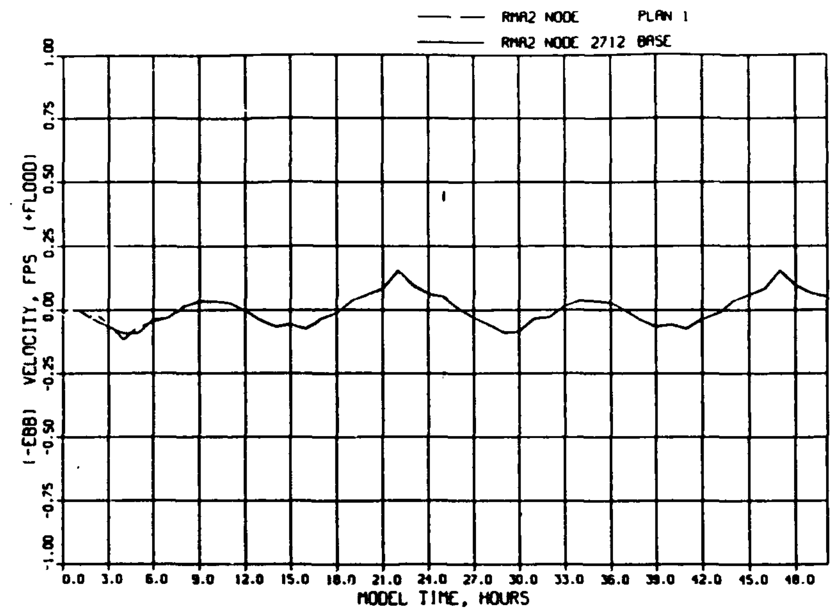
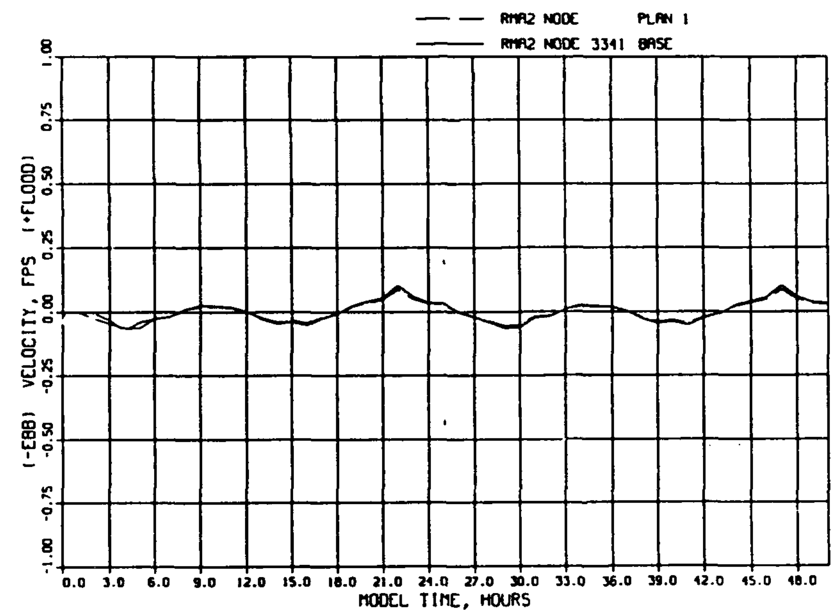


Figure A9. Velocity data, existing versus Plan 1 (Sheet 1 of 3)





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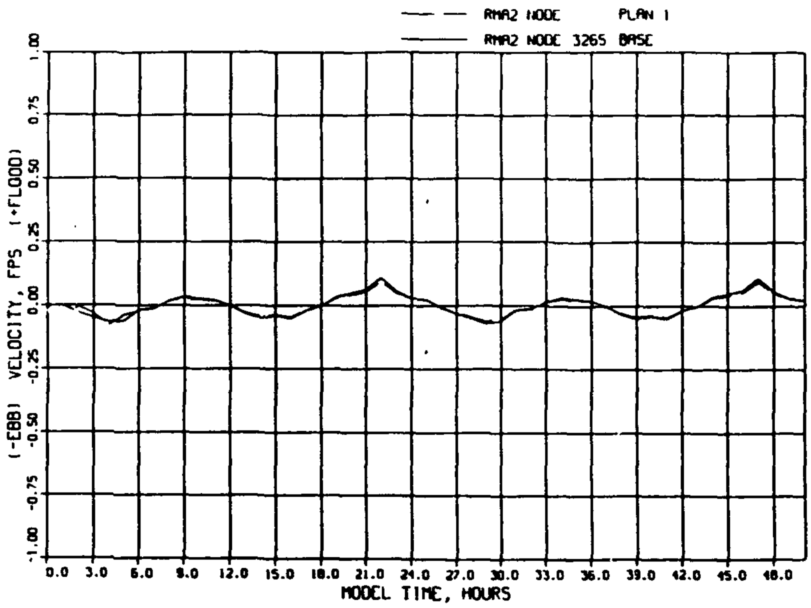

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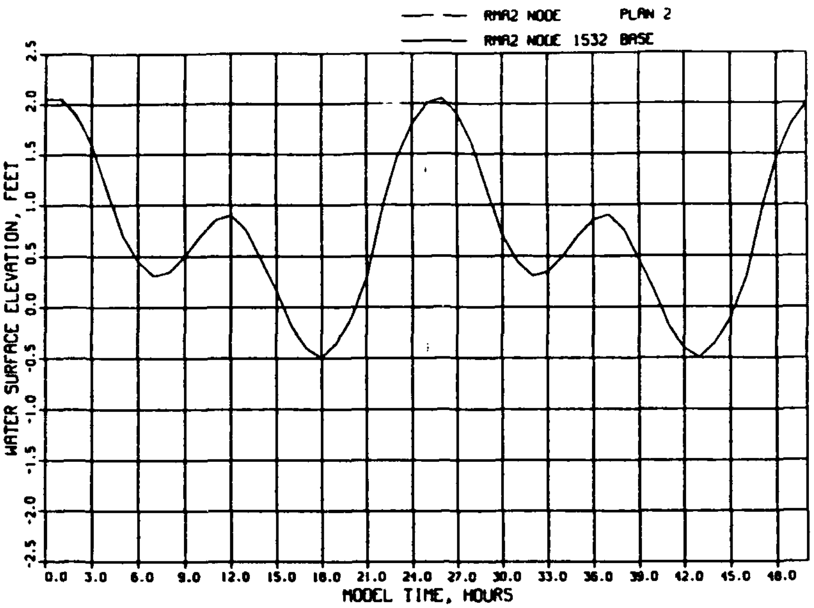


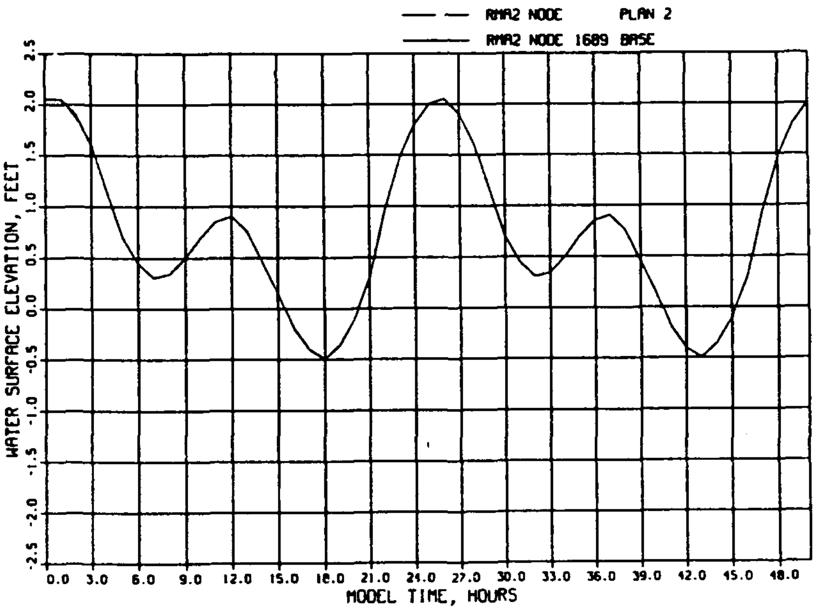
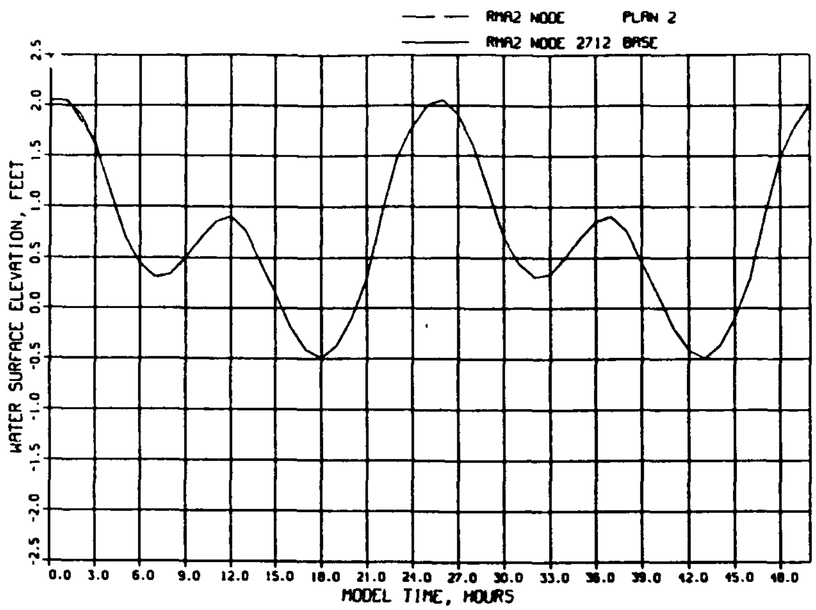
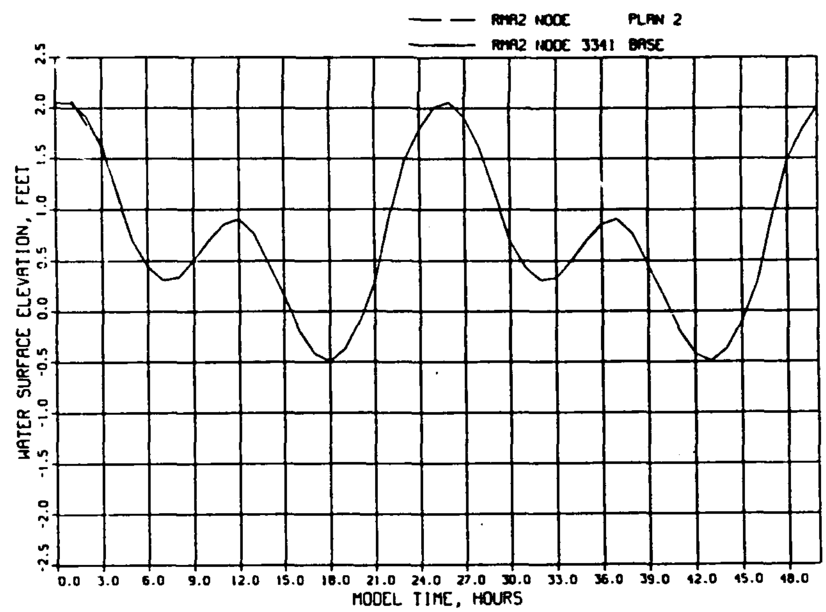


Figure A10. Water surface data, existing versus Plan 2 (Sheet 1 of 3)





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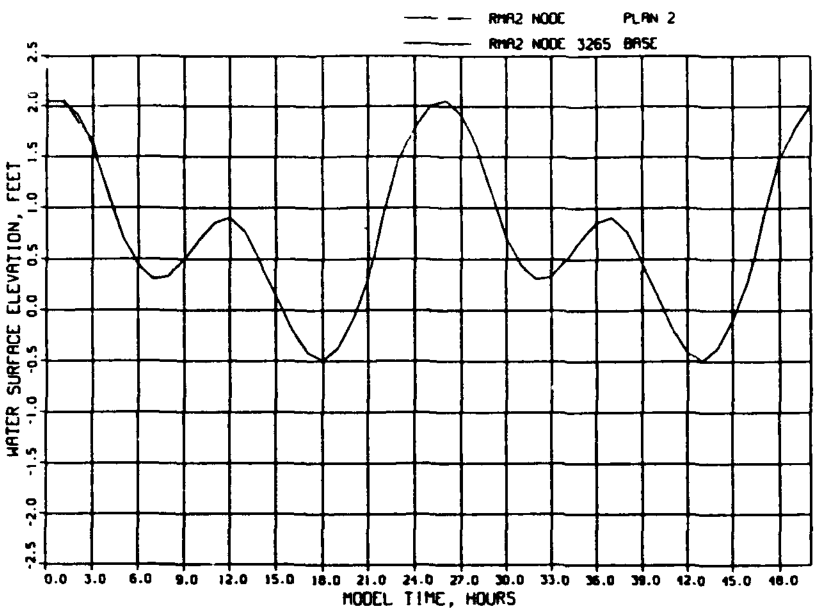

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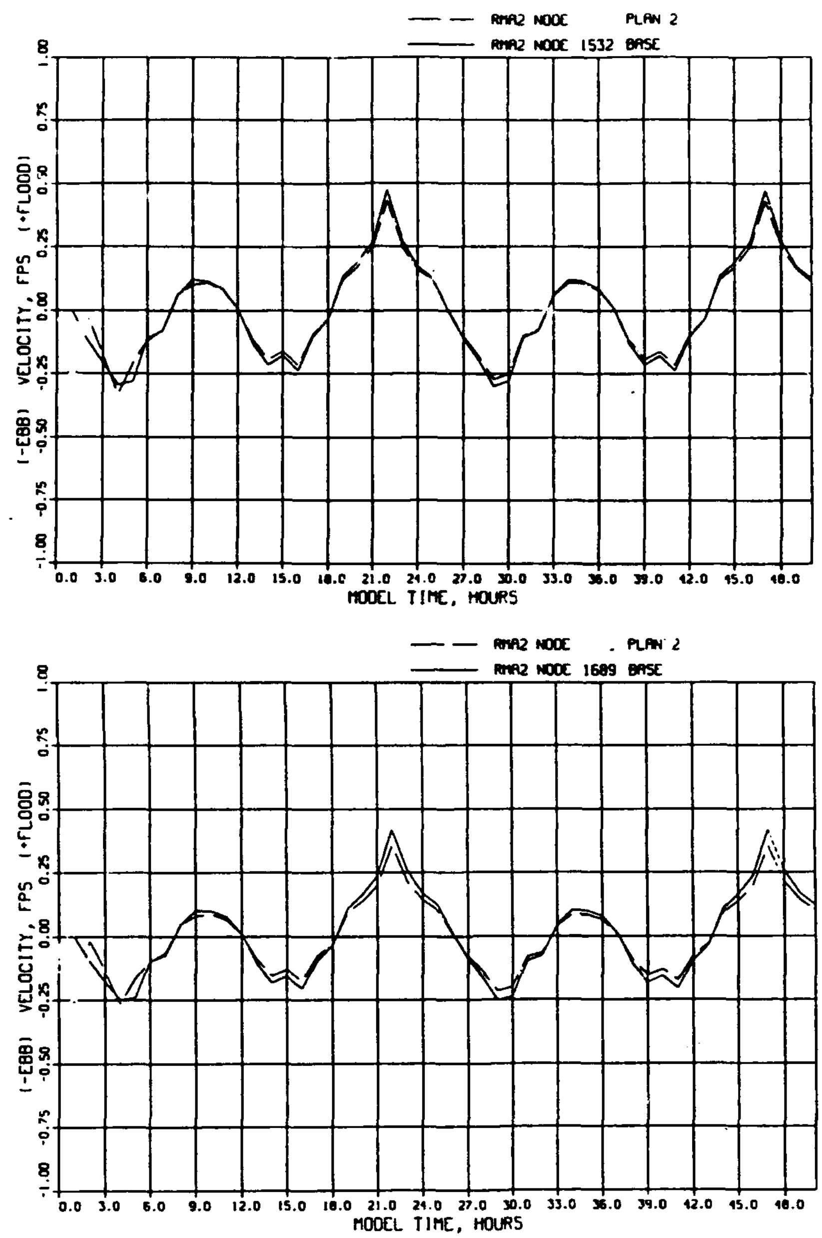
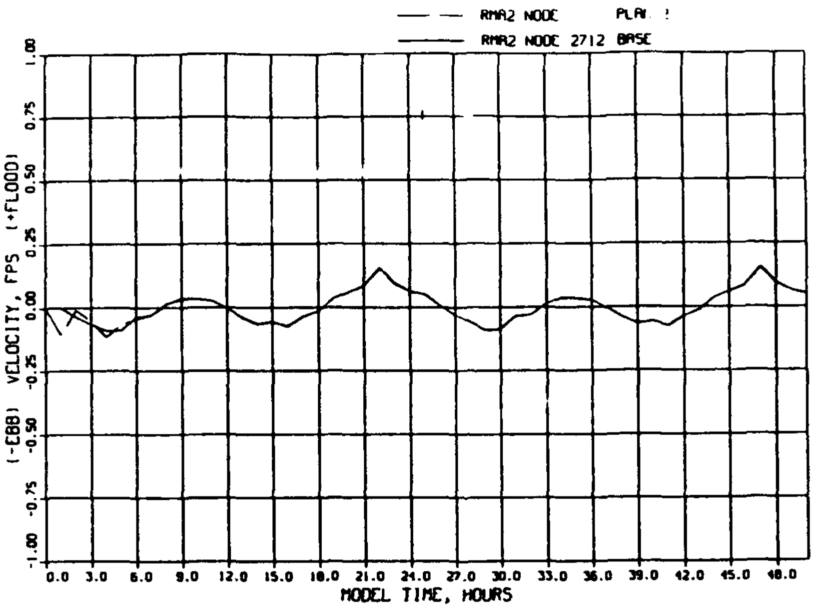
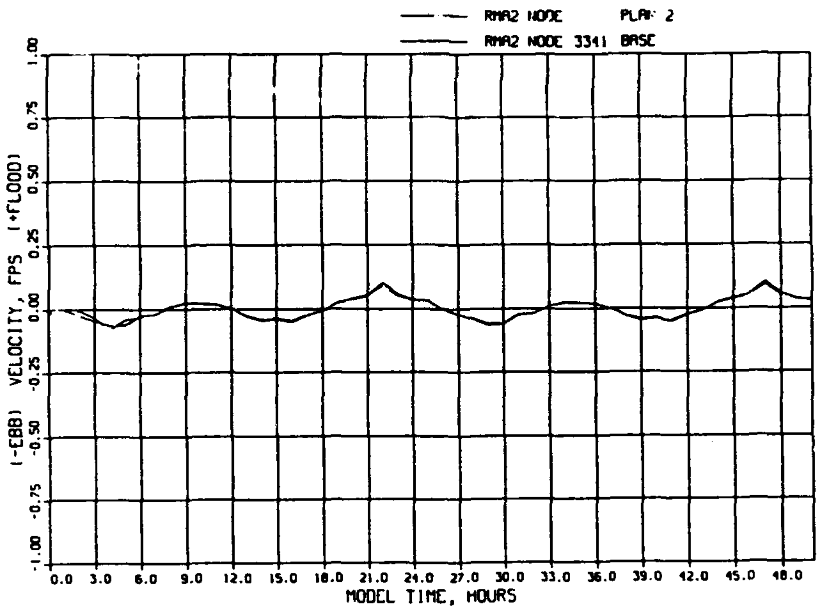


Figure A11. Velocity data, existing versus Plan 2 (Sheet 1 of 3)





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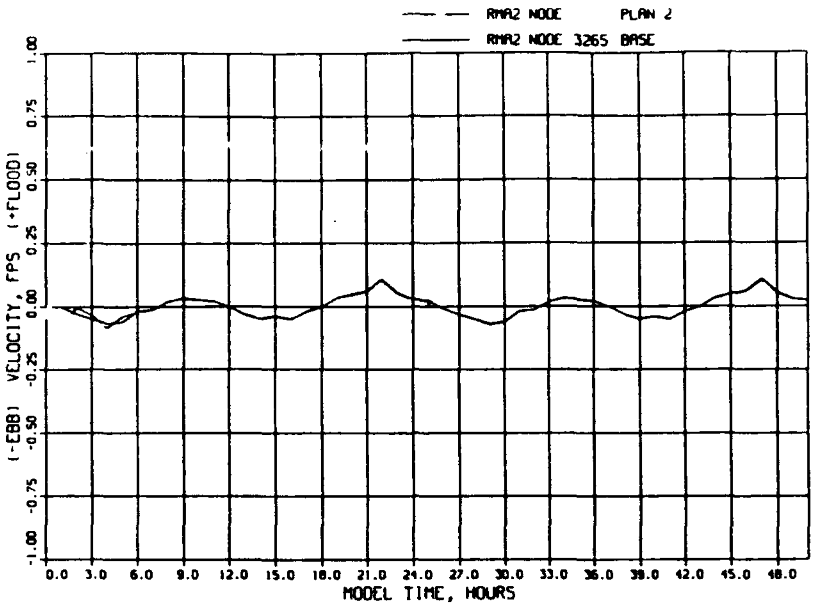

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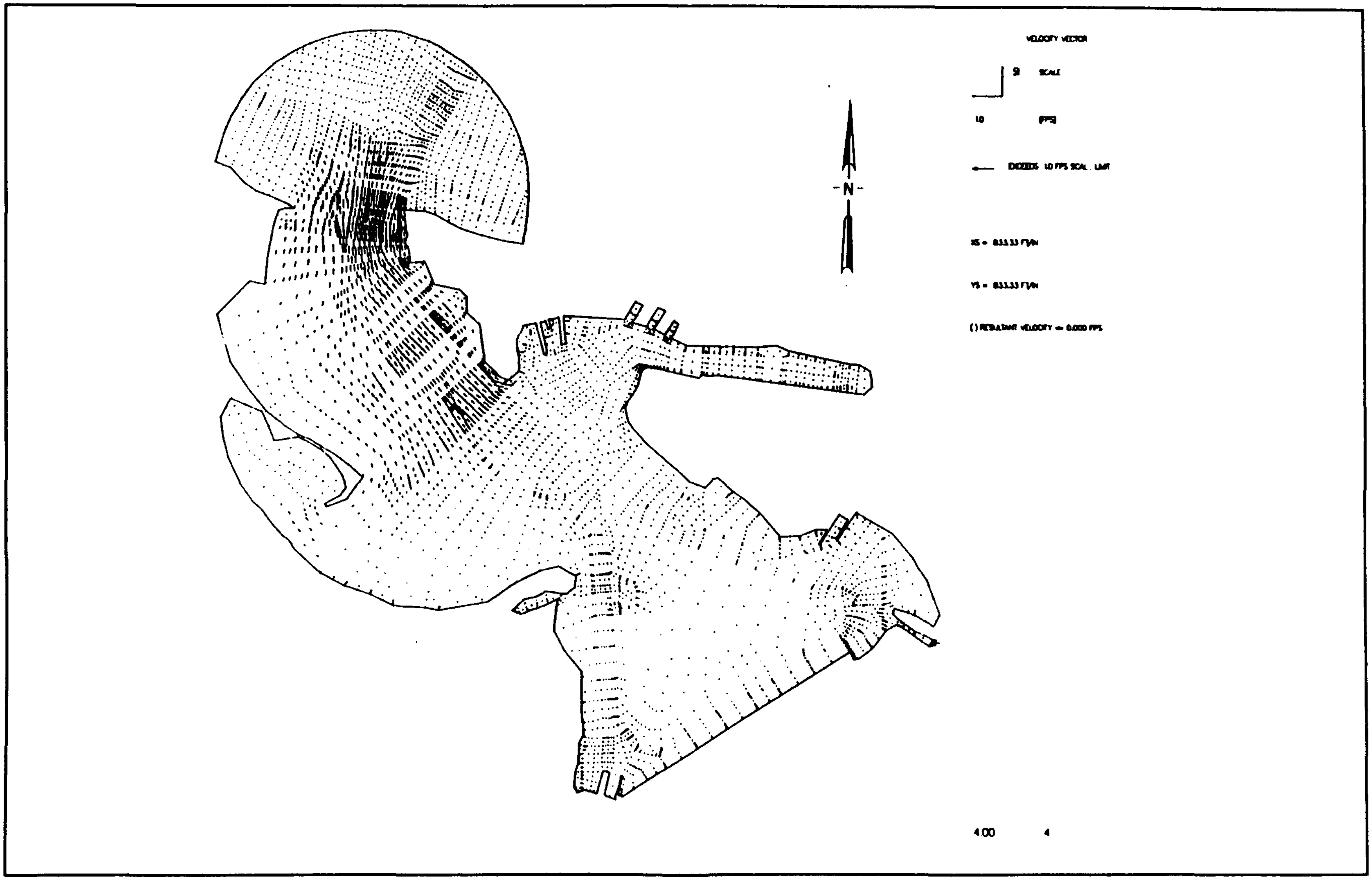

Figure A12. Vector plot - hour 4 - maximum ebb - base

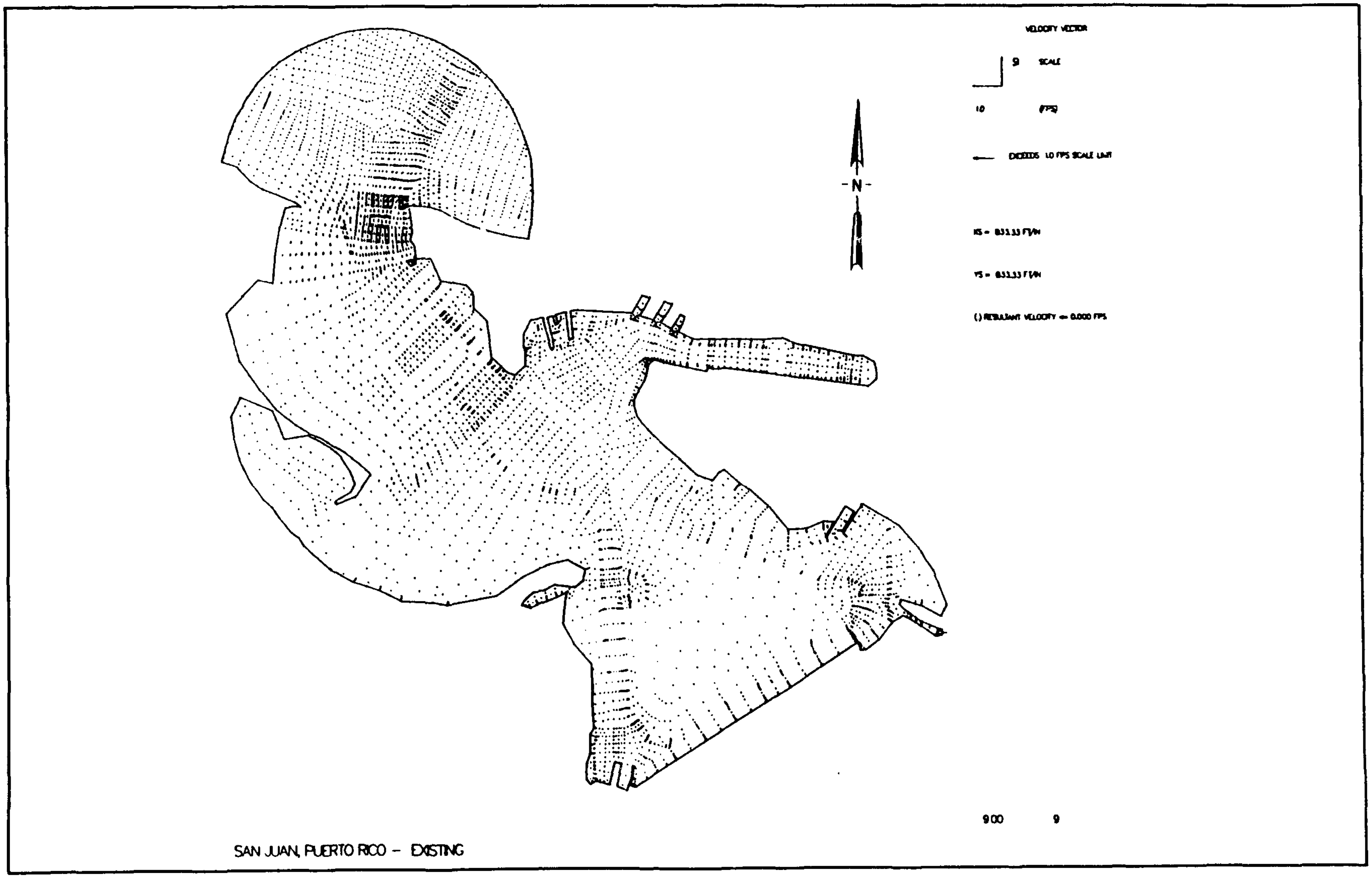

Figure A13. Vector plot - hour 9 - flood - base

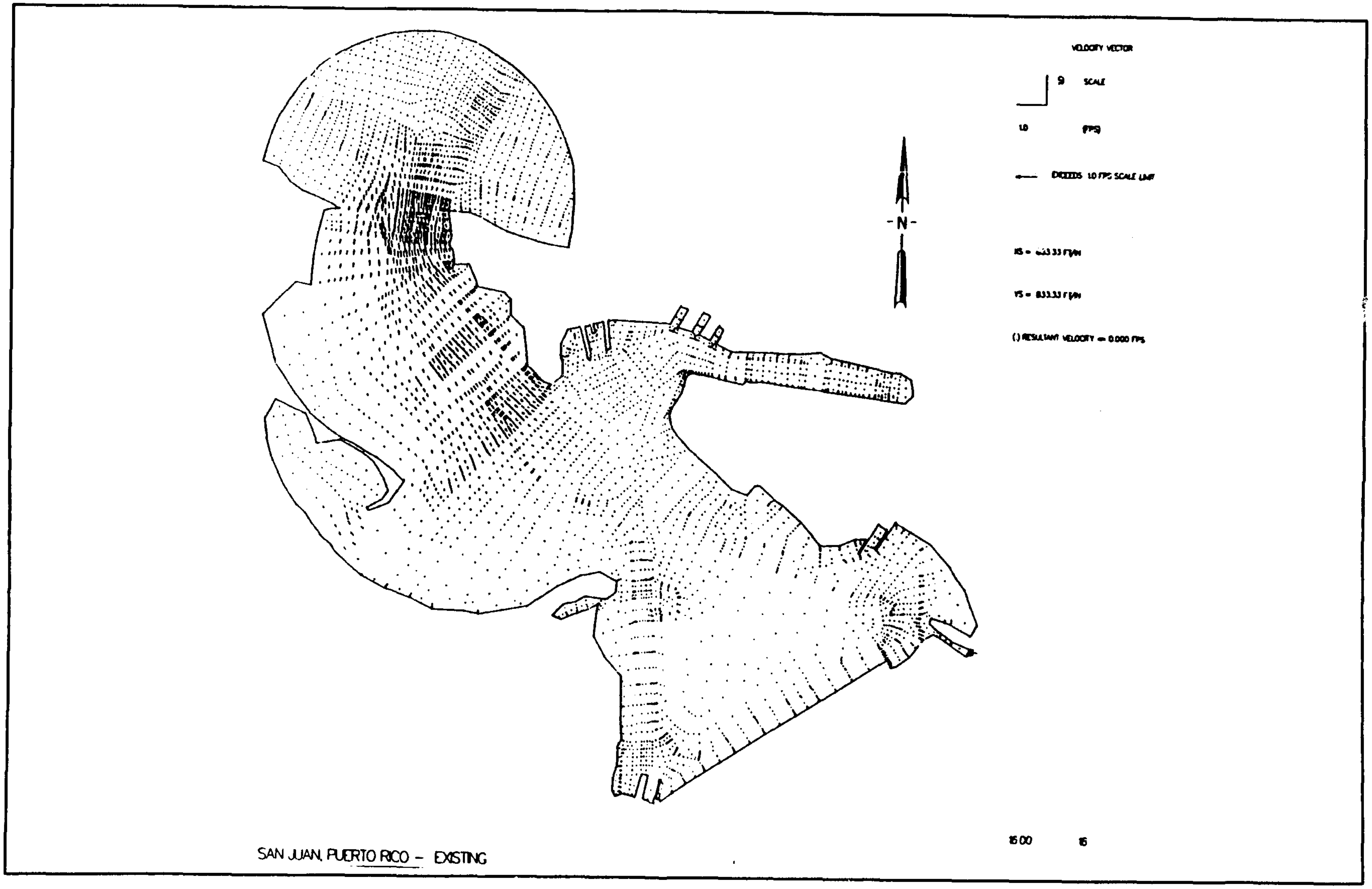

Figure A14. Vector plot - hour 16 - ebb - base

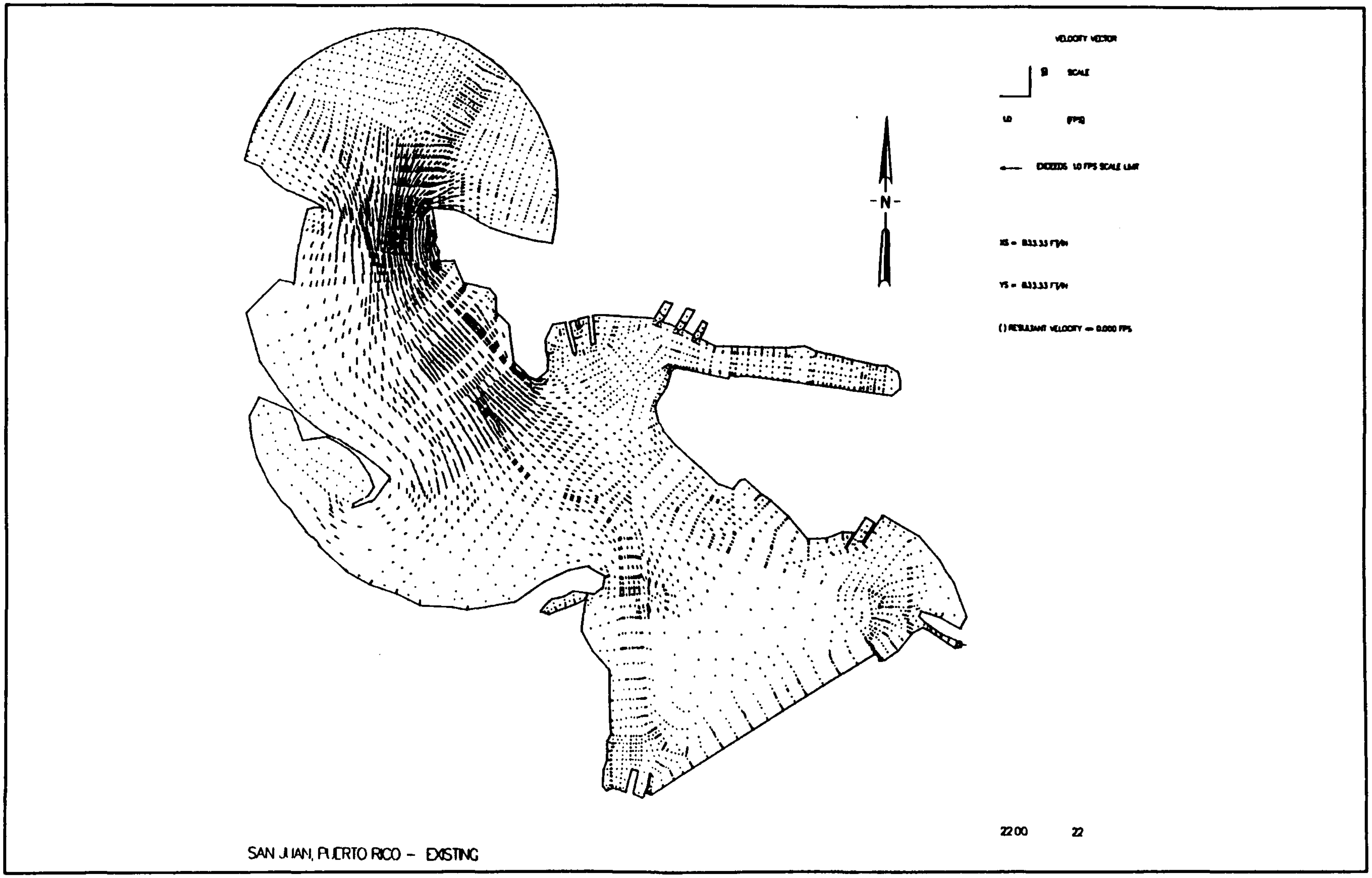

Figure A15. Vector plot - hour 22 - maximum flood - base

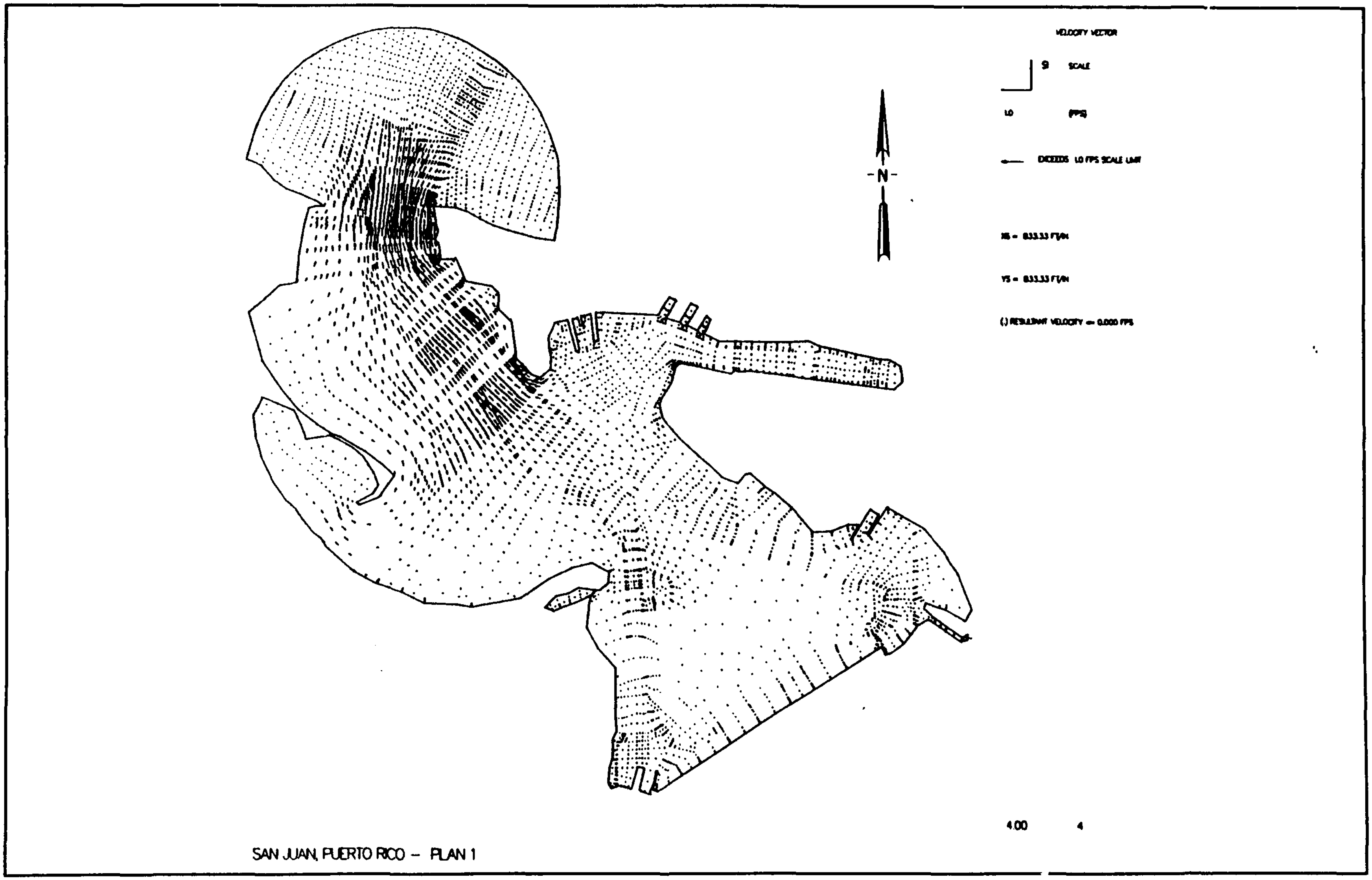

Figure A16. Vector plot - hour 4 - maximum ebb - plan 1

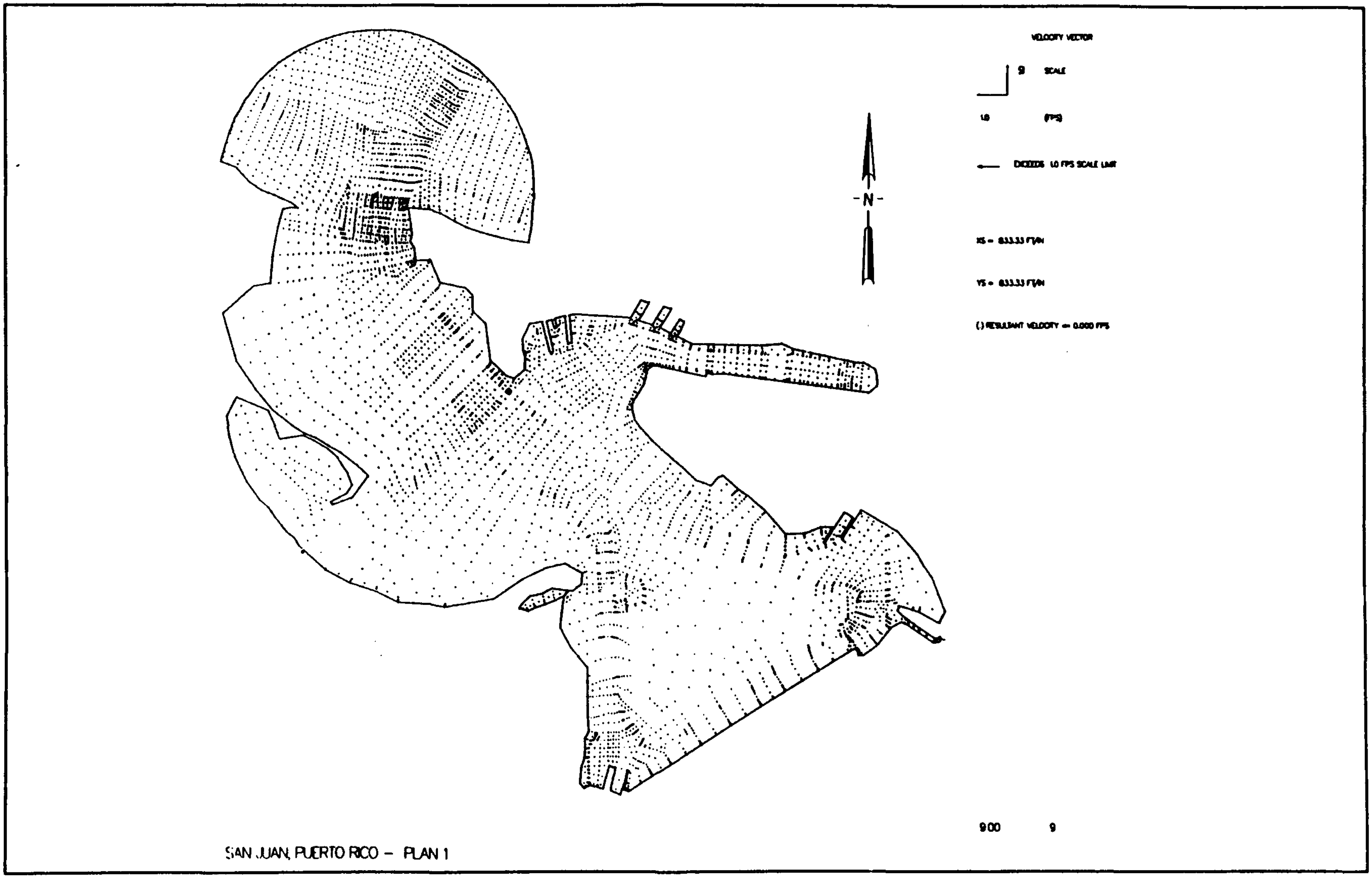

Figure A17. Vector plot - hour 9 - flood - plan 1

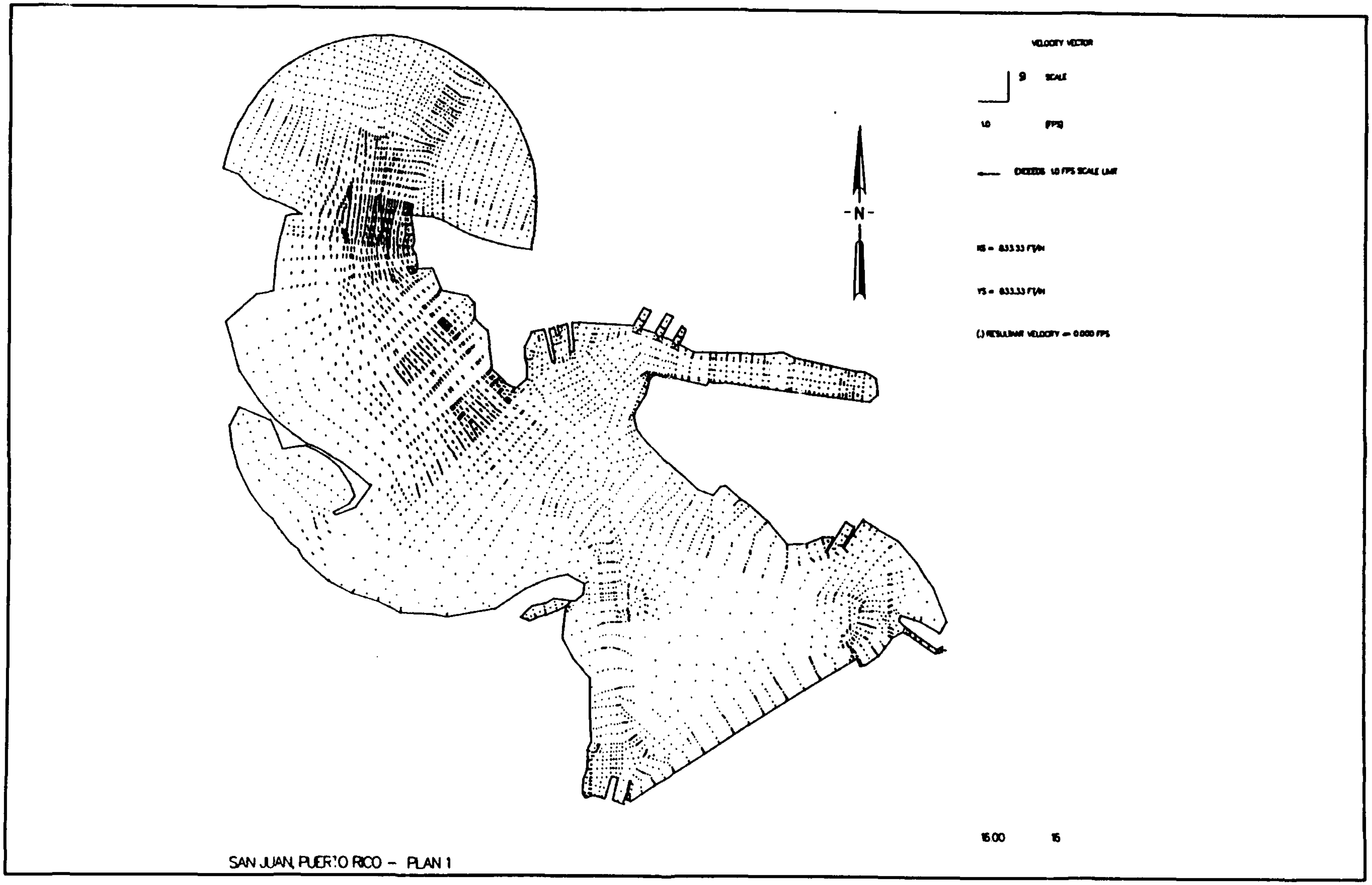

Figure A18. Vector plot - hour 16 - ebb - plan 1

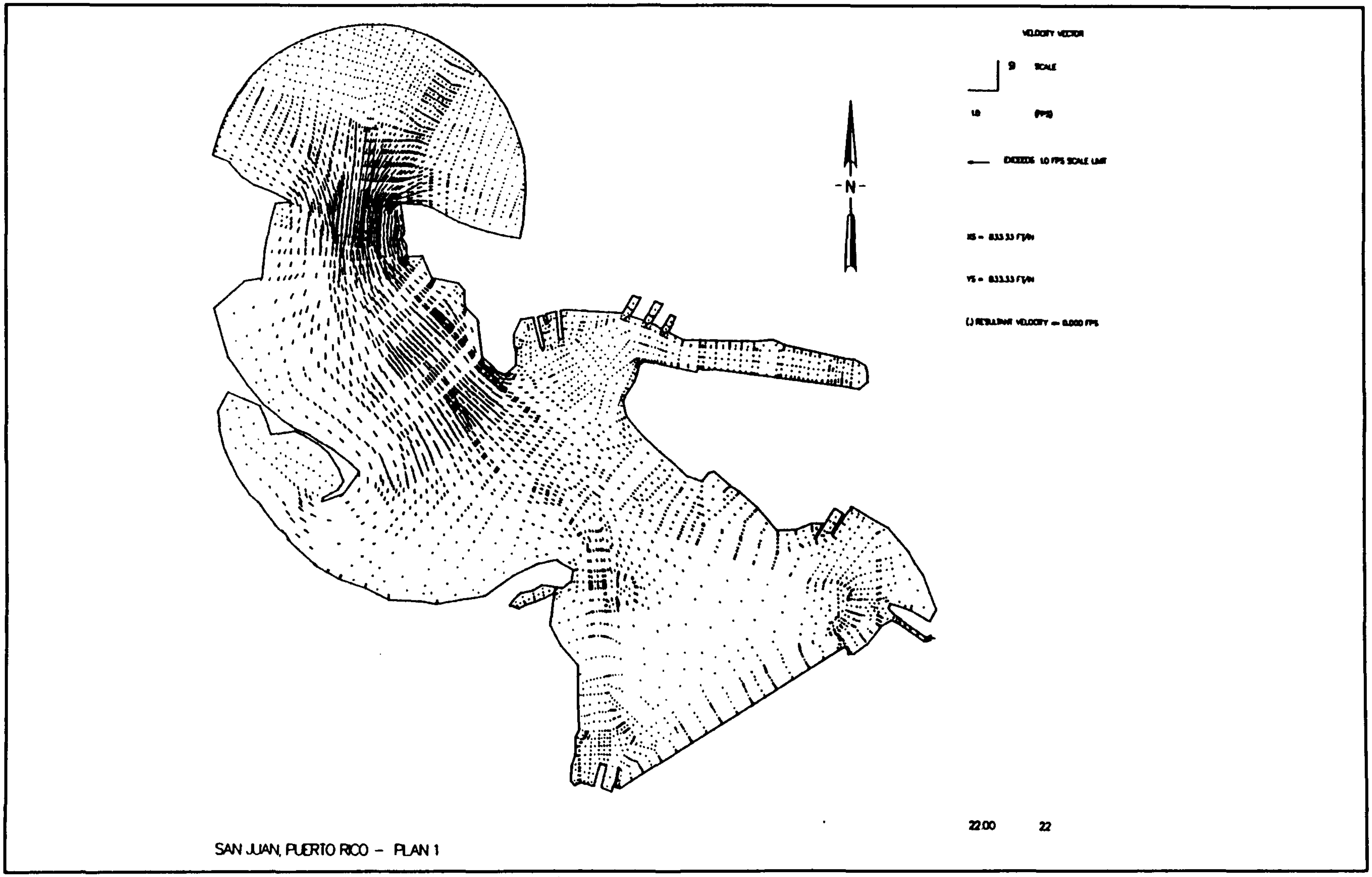

Figure A19. Vector plot - hour 22 - maximum flood - plan 1

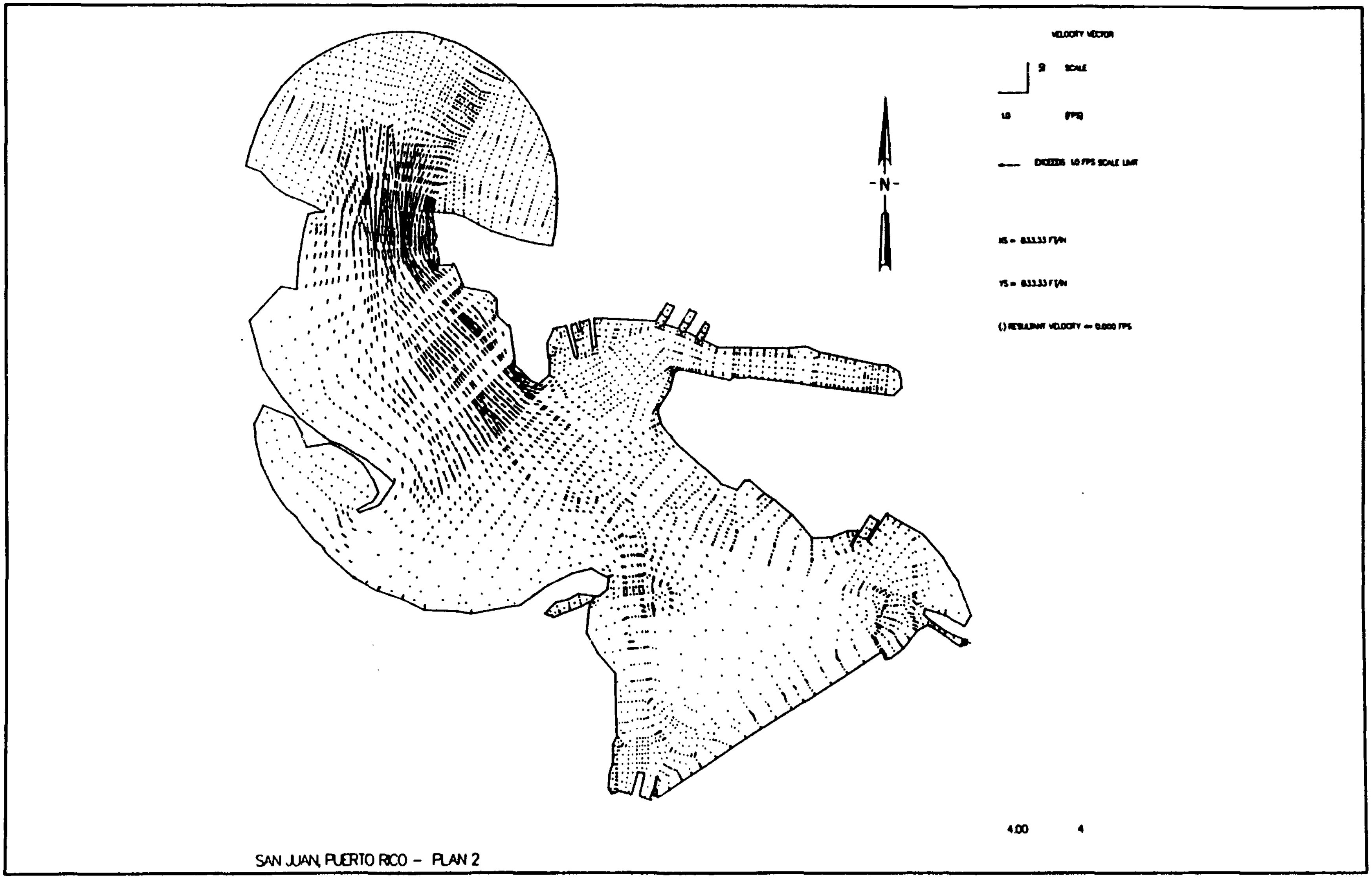

Figure A20. Vector plot - hour 4 - maximum ebb - plan 2

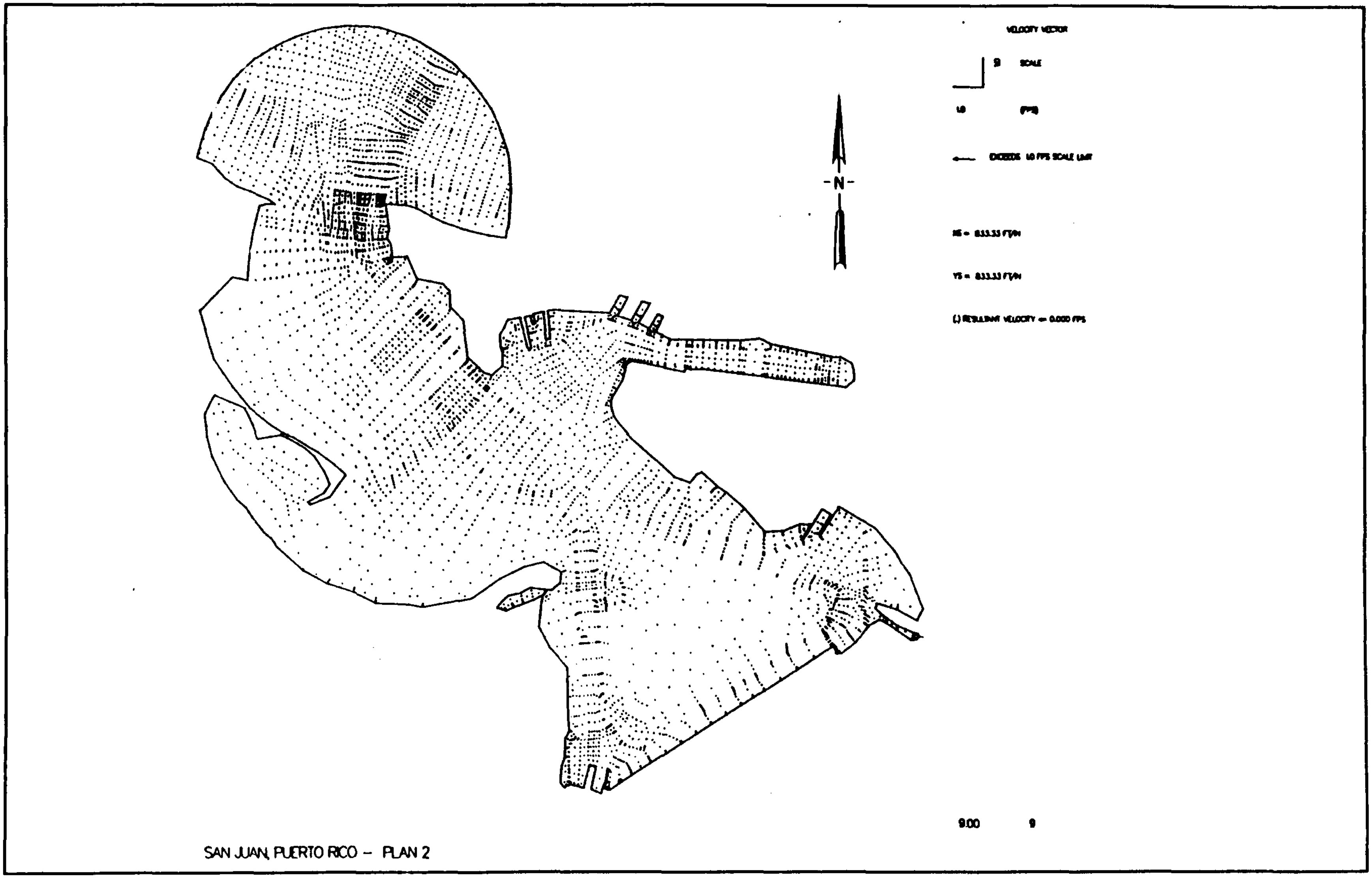

Figure A21. Vector plot - hour 9 - flood - plan 2

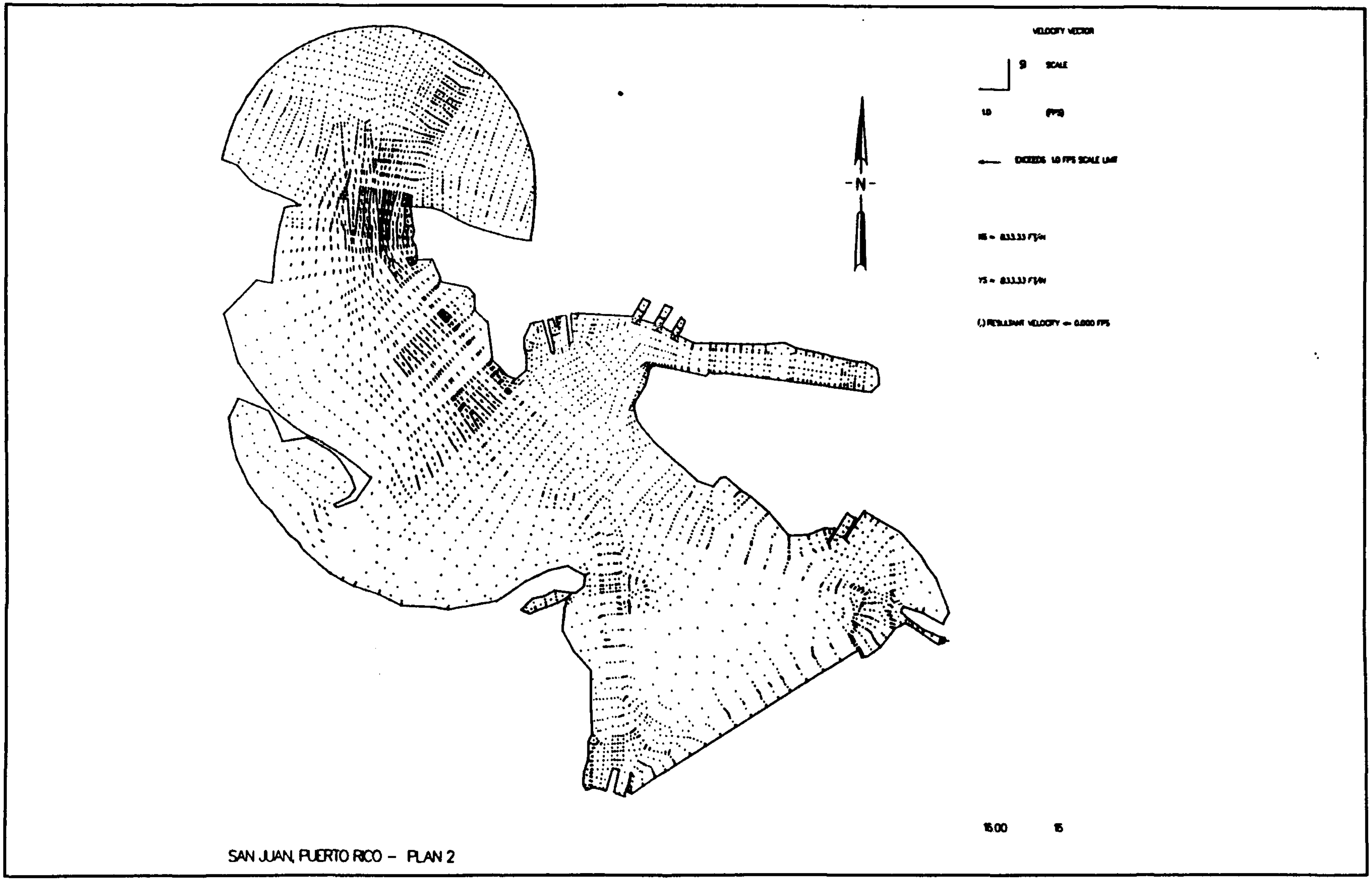

Figure A22. Vector plot - hour 16 - ebb - plan 2

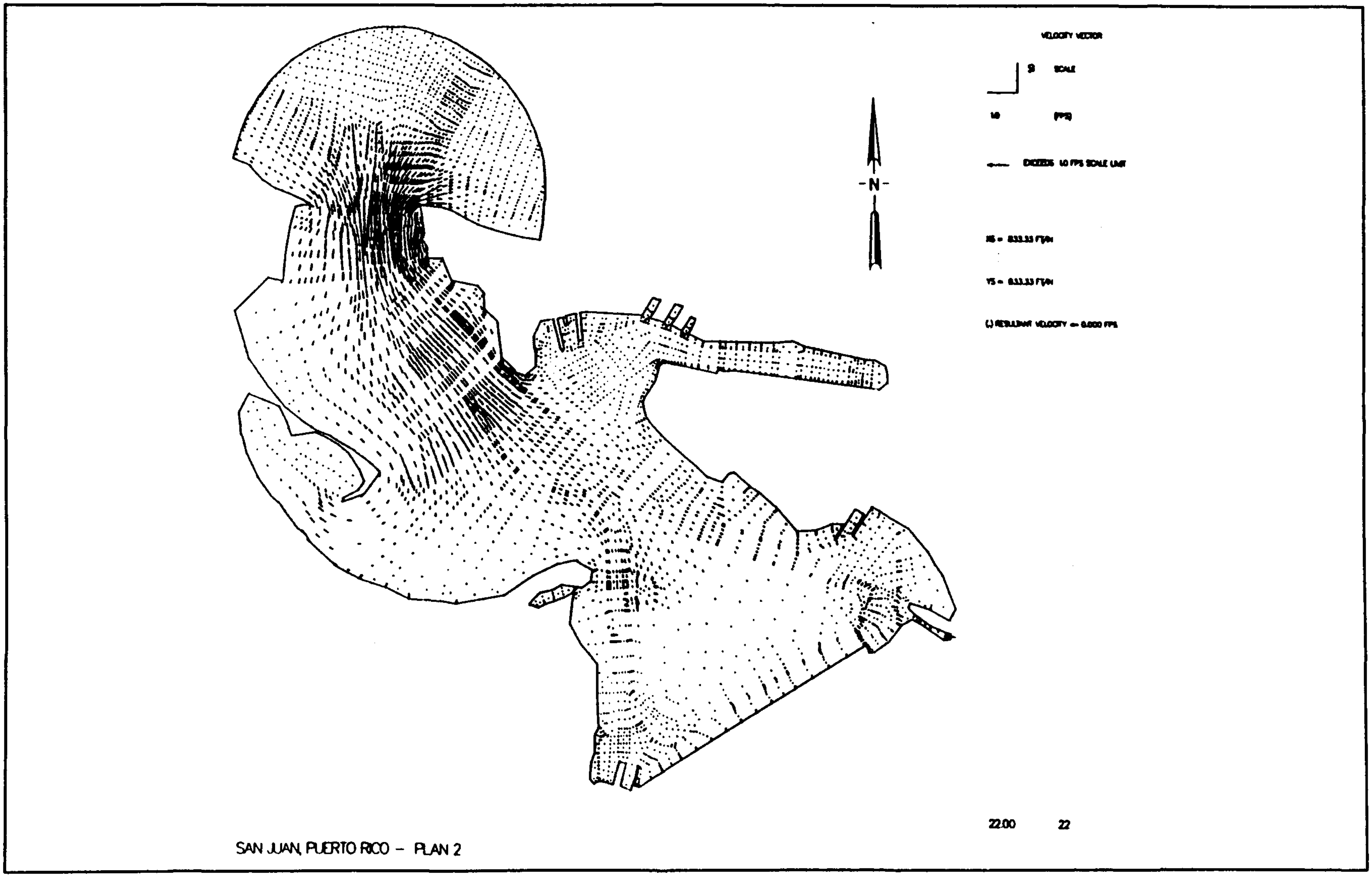

Figure A23. Vector plot - hour 22 - maximum flood - plan 2

Table A1
Model Velocities,[1] fps, Base Versus Plans

Node	Number	Hour 4 (-)	Hour 9 (+)	Hour 16 (-)	Hour 22 (+)
1532					
	Base	.29	.12	.24	.47
	Plan 1	.29	.09	.19	.39
	Plan 2	.33	.10	.22	.43
1689					
	Base	.25	.10	.21	.42
	Plan 1	.25	.07	.16	.33
	Plan 2	.27	.08	.17	.36
2712					
	Base	.09	.04	.08	.16
	Plan 1	.12	.03	.07	.15
	Plan 2	.12	.03	.07	.15
3341					
	Base	.06	.03	.05	.10
	Plan 1	.07	.02	.04	.09
	Plan 2	.08	.02	.05	.09
3265					
	Base	.07	.03	.05	.11
	Plan 1	.08	.03	.05	.10
	Plan 2	.08	.03	.05	.10

[1]Velocities are expressed to two decimal places to show changes only; model was unverified.

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13. ABSTRACT *(Maximum 200 words)*
A real-time ship simulation investigation of the proposed design for deepening and widening the man-made San Juan Harbor channels, San Juan, Puerto Rico, was conducted. The purposes of the study were to determine the required channel width and alignment to deepen the inner harbor channels from 36 to 39 ft and to determine the necessary depths in the entrance channel to allow for the ship's vertical motion due to wave action. A numerical model of the existing channel from the Atlantic Ocean to the inner harbor area was developed. This model was verified by two members of the San Juan Harbor Pilots Association. Numerical models of two plans were also developed. Tests were conducted in Vicksburg, MS, on the U.S. Army Engineer Waterways Experiment Station ship simulator.

These tests determined the optimum width and alignment for the San Juan Harbor channels.

14. SUBJECT TERMS
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Port of San Juan
San Juan Harbor
Ship simulation

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